

(photo in APS 2008 calendar)

SciBooNE Neutrino Experiment at Fermilab

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Columbia University

Neutrino Frontiers at Minnesota, Oct. 26, 2008

Outline

- Introduction
- SciBooNE Experiment
- Preliminary results
- Summary

What's SciBooNE?

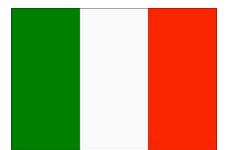
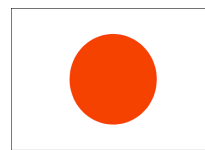
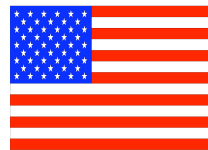
- Neutrino experiment at Fermilab (E954)
- Precision measurement of ν and $\bar{\nu}$ -nucleus cross section around 1GeV.
 - Important for accelerator based neutrino oscillation experiments.



SciBooNE Collaboration

- Universitat Autònoma de Barcelona
- University of Cincinnati
- University of Colorado, Boulder
- Columbia University
- Fermi National Accelerator Laboratory
- High Energy Accelerator Research Organization (KEK)
- Imperial College London
- Indiana University
- Institute for Cosmic Ray Research (ICRR)
- Kyoto University
- Los Alamos National Laboratory
- Louisiana State University
- Purdue University Calumet
- Università degli Studi di Roma "La Sapienza and INFN"
- Saint Mary's University of Minnesota
- Tokyo Institute of Technology
- Universidad de Valencia

5 countries 17 institutions



Spokespeople:

M.O. Wascko (Imperial), T. Nakaya (Kyoto)

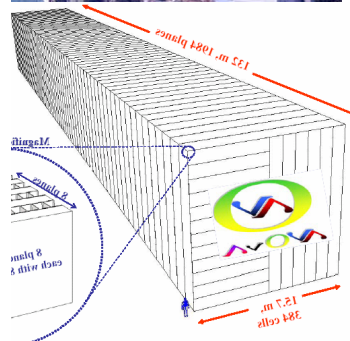
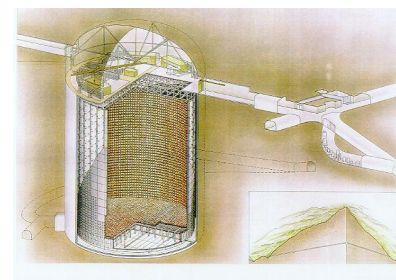
Introduction



Next step...

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U_{MNS} V_M^{CP} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$c_{ij} = \cos \theta_{ij}$
 $s_{ij} = \sin \theta_{ij}$



$$U_{MN} = \begin{bmatrix} 1 & 0 & 0 \\ c_{13} & 0 & s_{13}e^{-i\delta} \\ c_{13} & s_{12} & 0 \end{bmatrix}$$

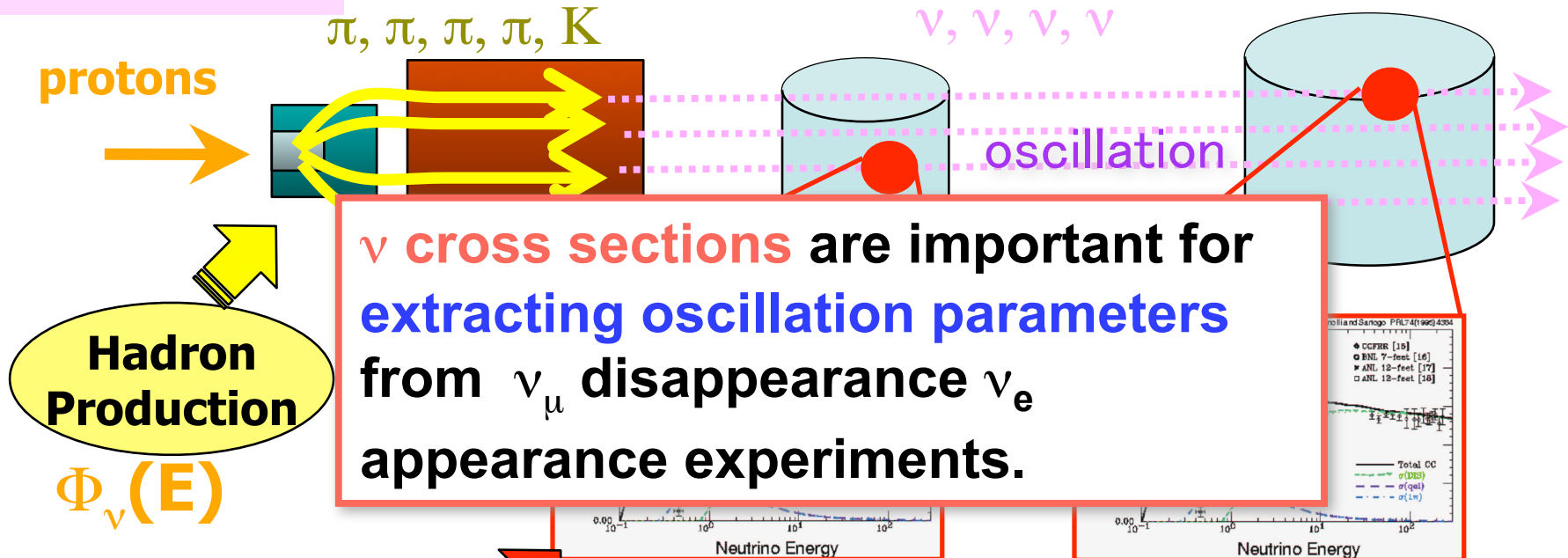
Precision measurement of oscillation parameters

- Discover the last oscillation channel
 - θ_{13}
- CP violation in the lepton sector $(\nu, \bar{\nu})$
 - δ
- Mass hierarchy
 - The sign of Δm_{23}^2
- Test of the standard ν oscillation scenario (U_{MNS})
 - Precise measurements of ν oscillations ($\pm \Delta m_{23}^2, \theta_{23}$)

Strategy of accelerator ν oscillation experiments

Intense beam

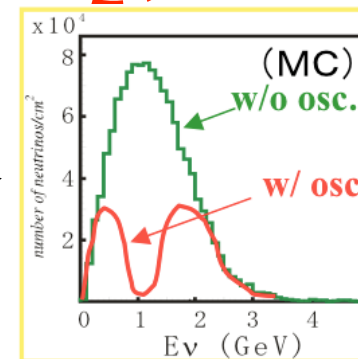
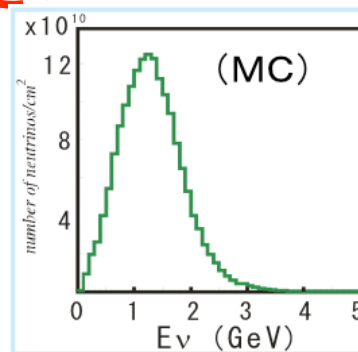
Gigantic detector



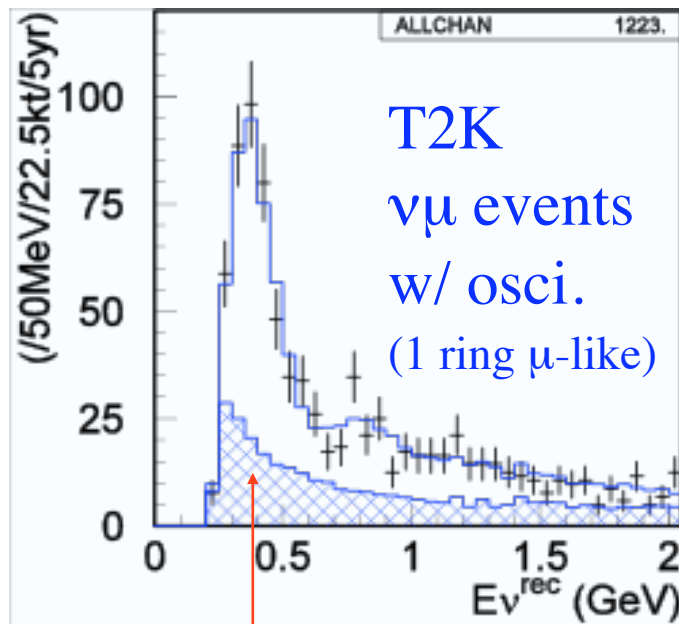
Hadron Production
 $\Phi_\nu(E)$

X-section
 $\sigma(\nu N)$

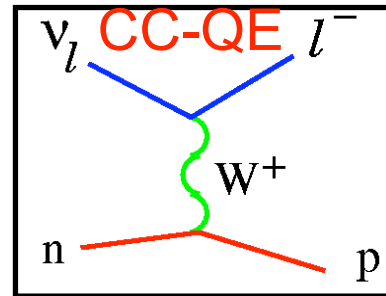
$$(\sigma(E)) \times \Phi_\nu^{\text{near}}(E) \Leftrightarrow (\sigma(E)) \times \Phi_\nu^{\text{far}}(E)$$



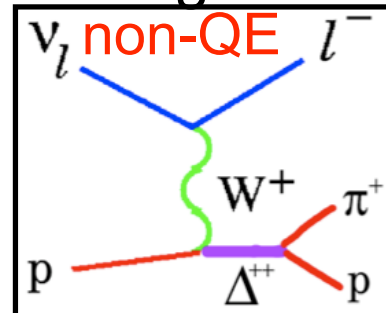
Impact of ν cross section



Signal



Background



–Signal: **CC-QE**

($\nu+n \rightarrow \mu+p$; Energy Reconstruction from μ kin.)

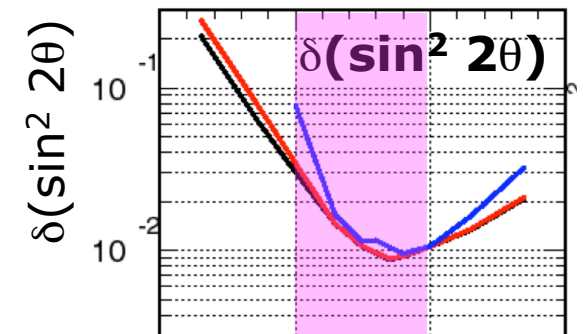
–Background: **non-QE**; Mainly **CC- $1\pi^+$**

($\nu+N \rightarrow \mu+\pi+N'$)

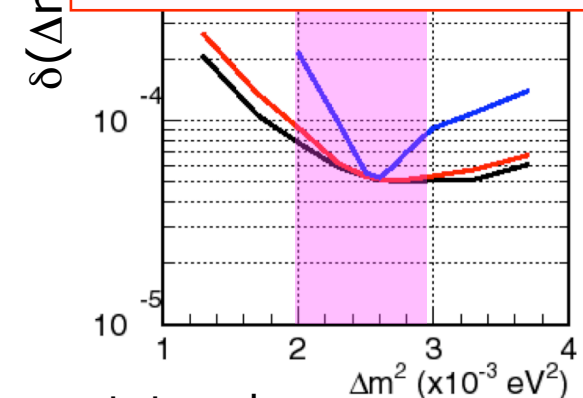
ν oscillation measurement requires precise knowledge on background.

$\nu_\mu \rightarrow \nu_x$ measurement

error (90%CL)



**T2K requires
<10% level
knowledge on
nonQE/QE**

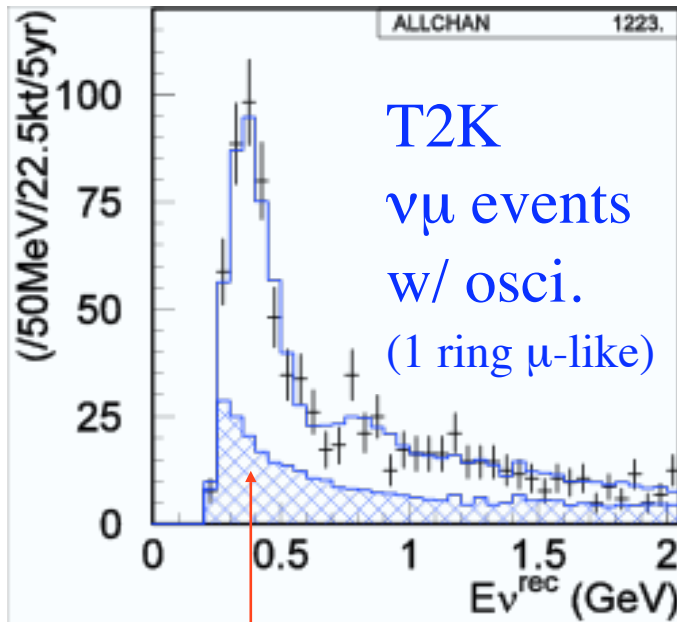


— stat. only

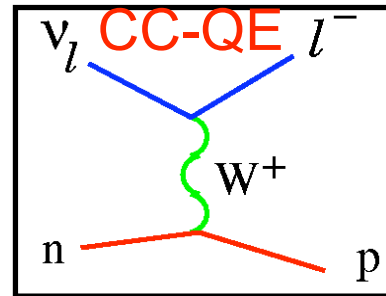
— $\delta(\text{nQE/QE}) = 5\%$

— $\delta(\text{nQE/QE}) = 20\%$

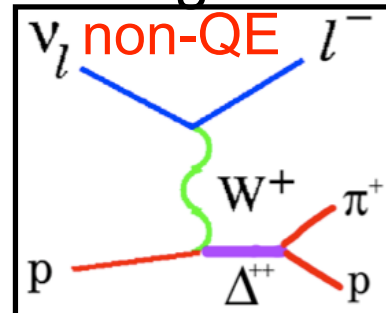
Impact of ν cross section



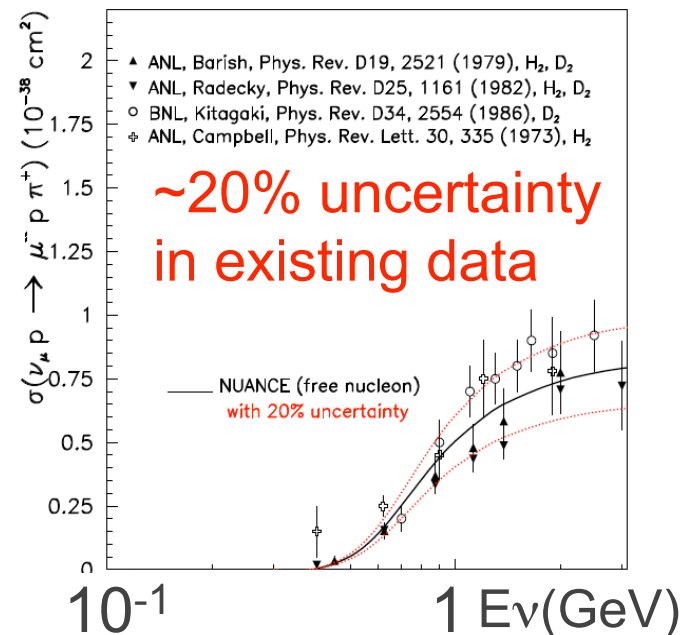
Signal



Background



CC- $1\pi^+$ cross section



Need new measurement
of non-QE cross sections

–Signal: **CC-QE**

($\nu+n \rightarrow \mu+p$; Energy Reconstruction from μ kin.)

–Background: **non-QE**; Mainly **CC- $1\pi^+$**

($\nu+N \rightarrow \mu+\pi+N'$)

ν oscillation measurement requires
precise knowledge on background.

Other $\nu/\bar{\nu}$ interactions

- Neutral current π^0 prod.

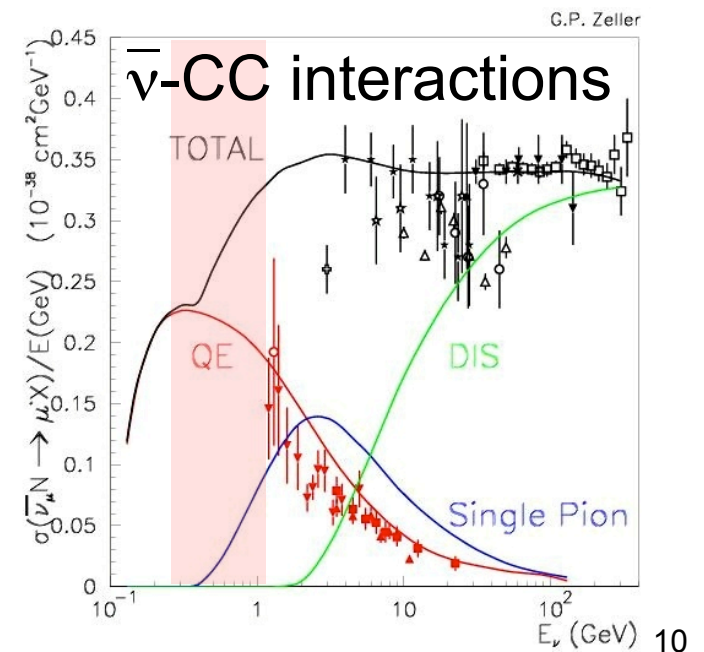
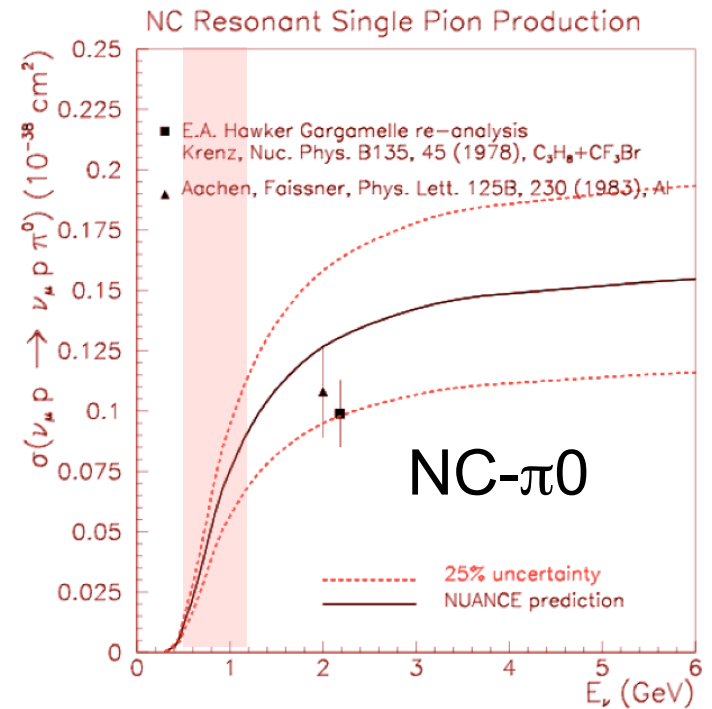
$$(\nu + N \rightarrow \nu + \pi^0 + N')$$

← Background for ν_e appearance search

- Anti-neutrino interactions

- No measurement below 1 GeV

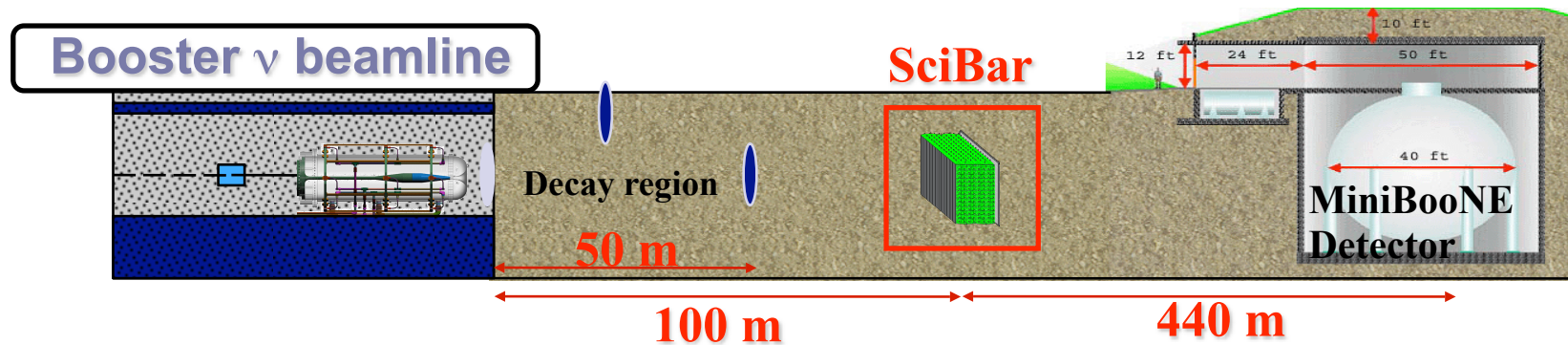
← Important for $\bar{\nu}$ oscillation study (CPV) in T2K-II



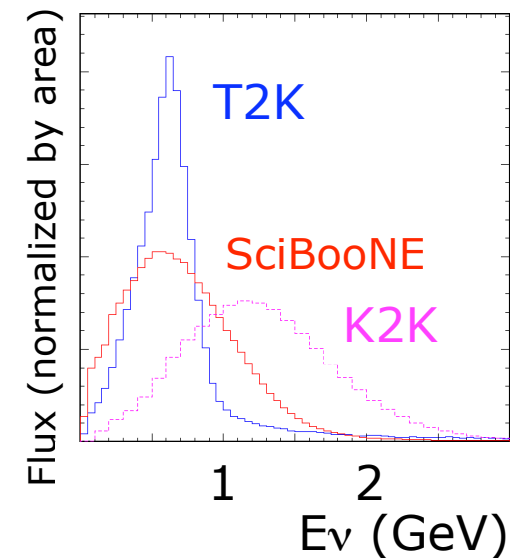
SciBooNE Experiment

SciBooNE Experiment

(K2K-SciBar detector at FNAL Booster Neutrino Beam line)

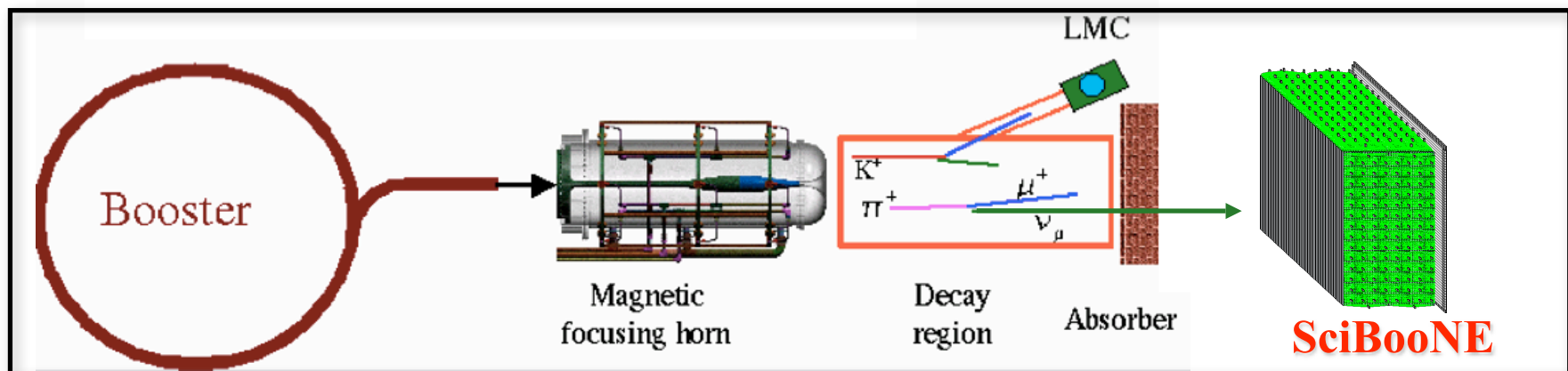
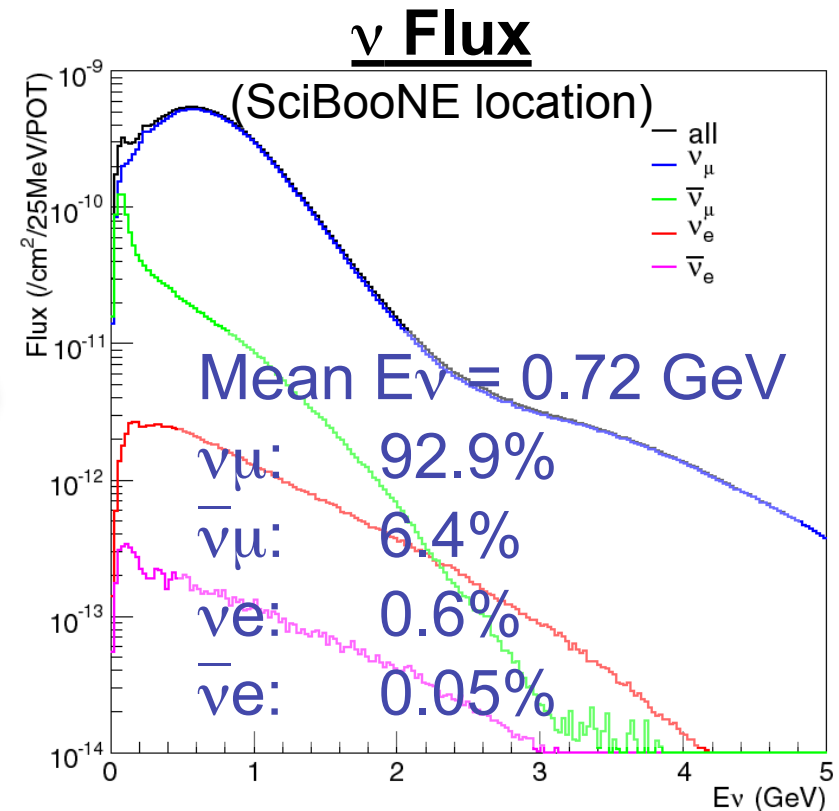
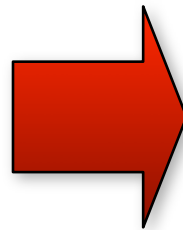


- Precision measurement of ν & $\bar{\nu}$ cross sections at $\sim 1\text{ GeV}$ ← Important for T2K and other oscillation experiments
- SciBar:
 - Originally K2K-near detector
 - Shipped to FNAL
- BNB: Intense & low energy ν beam
 - E_ν good match to T2K
 - ν and $\bar{\nu}$ beam
- MiniBooNE near detector



Booster Neutrino Beam

- 8 GeV protons from **Booster**
- Protons hit beryllium target (71 cm long, 1 cm diameter) within a **magnetic focusing horn** and produce mesons
- The mesons decay into neutrinos in 50m **decay region**
- Neutrinos are observed in **SciBooNE** (100m)
- $\bar{\nu}$ beam by changing horn polarity



SciBooNE Detectors

SciBooNE detectors

SciBar: Fully active target & tracker

Total mass: 15t, Fiducial: ~10t

14,336 channels; extruded scintillator

Particle ID with dE/dx

EC: EM Calorimeter

Lead+scintillation fibers: $11X_0$

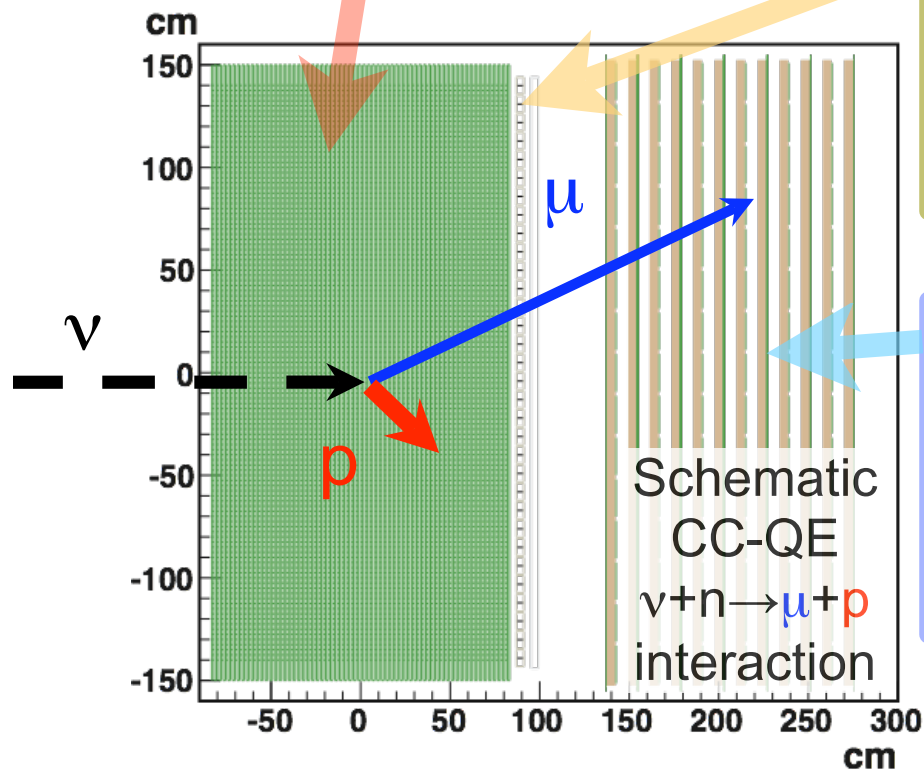
Gamma / electron ID

MRD: Muon Range Detector

Steel (5cm thick x12) +scintillator

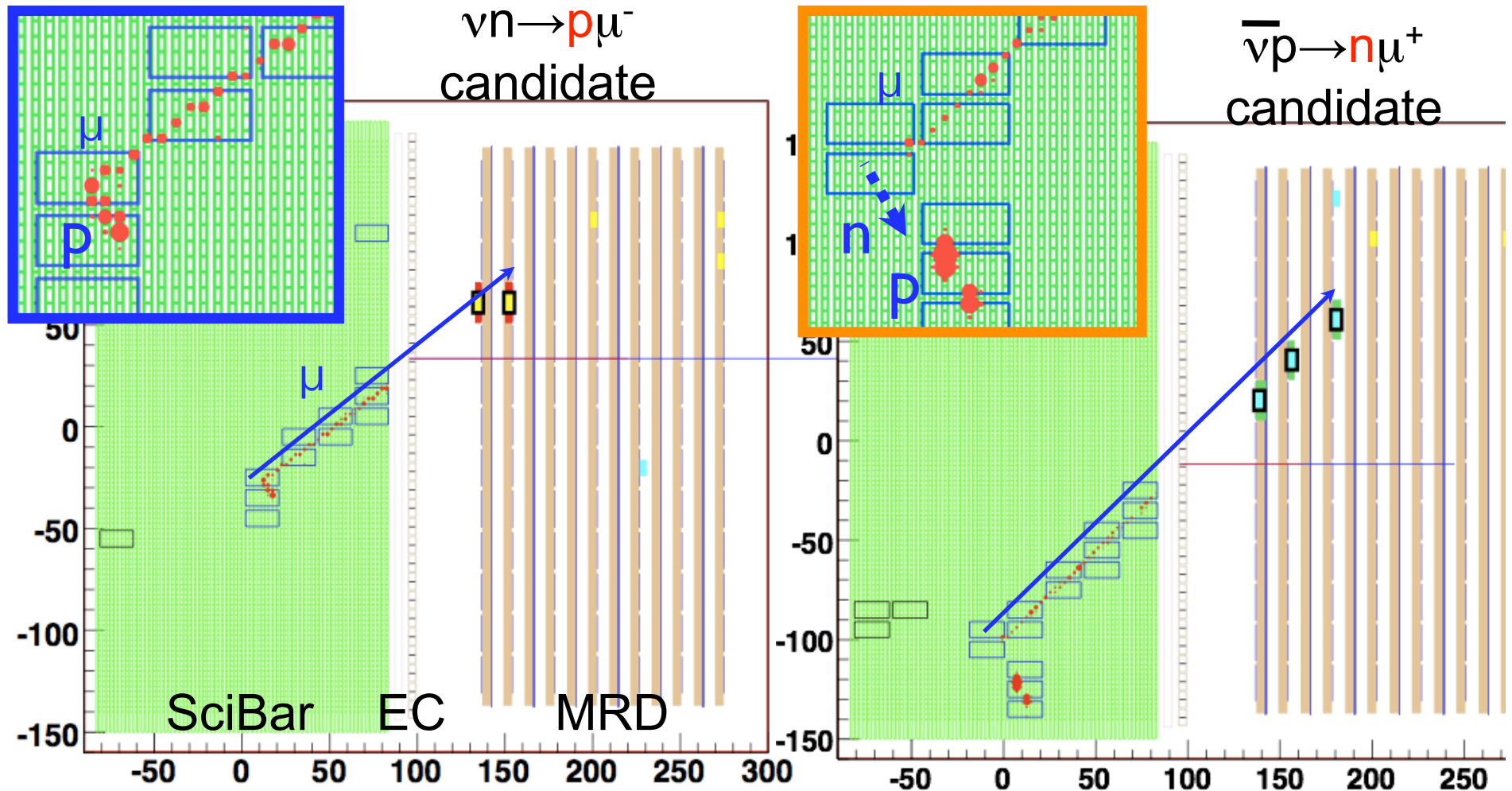
μ identification

Measure up to 1.2 GeV/c



ν events at SciBooNE

ν and $\bar{\nu}$ CCQE event candidates



SciBooNE data

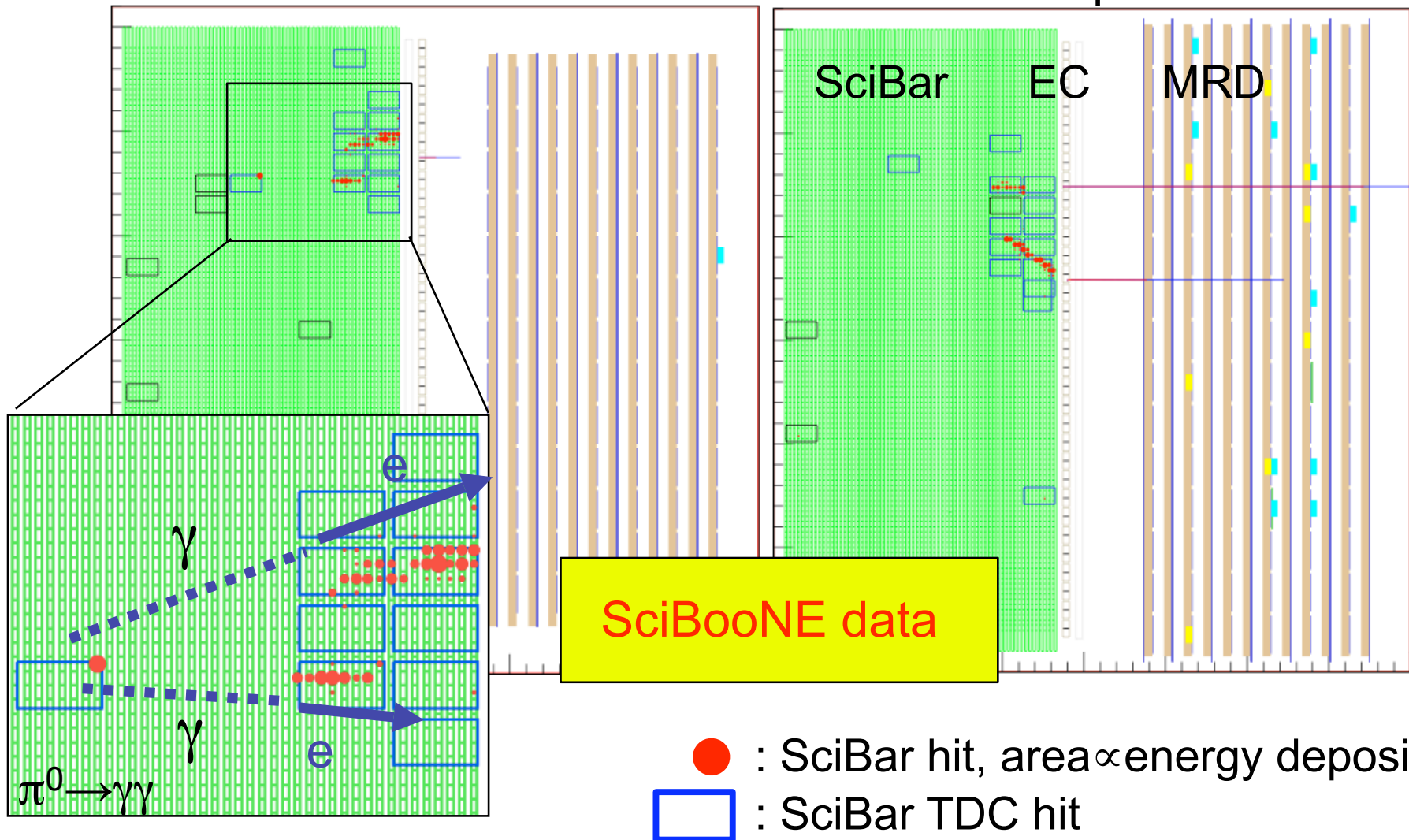
- : SciBar hit, $\text{area} \propto \text{energy deposit}$
- : SciBar TDC hit

NC- $1\pi^0$ event candidate

$$\nu + p \rightarrow \nu + \textcolor{red}{p} + \textcolor{red}{\pi^0}$$

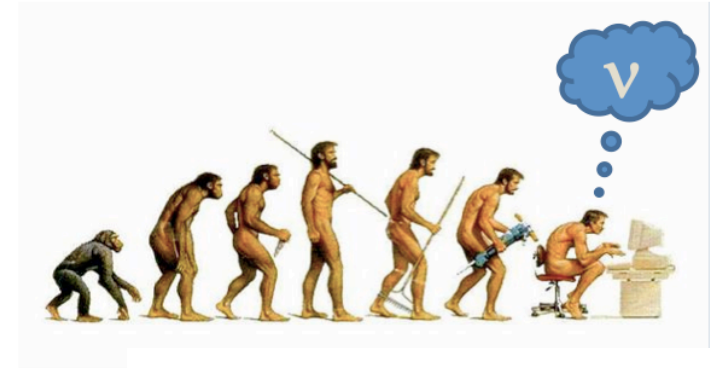
Side view

Top view



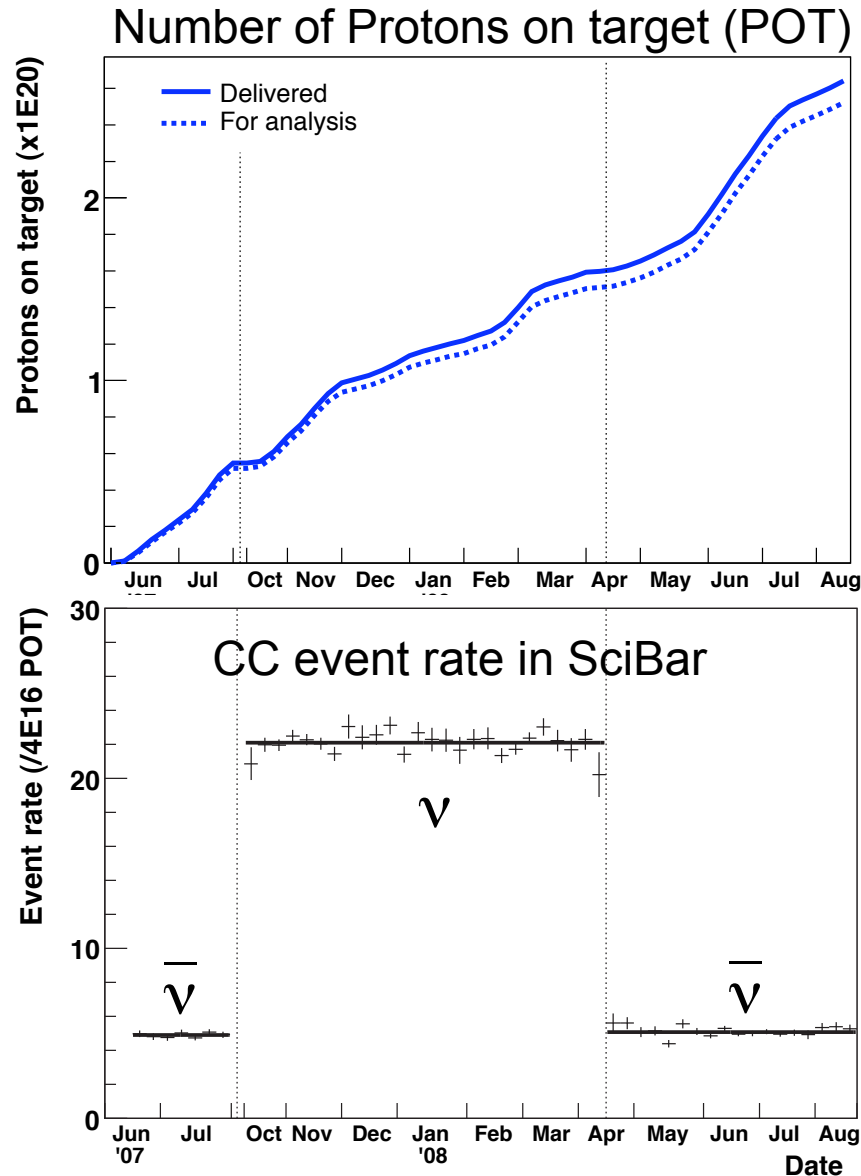
SciBooNE Timeline

- 2005, Summer - Collaboration formed
- 2005, Dec - Proposal
- 2006, Jul - Detectors move to FNAL
- 2006, Sep - Groundbreaking
- 2006, Nov - EC Assembly
- 2007, Feb - SciBar Assembly
- 2007, Mar - MRD Assembly
- 2007, Mar - Cosmic Ray Data
- 2007, Apr - Detector Installation
- 2007, May - Commissioning
- 2007, Jun - Start data taking (antineutrino Data Run)
- 2007, Oct - Neutrino Data Run
- 2008, Apr - Antineutrino Data Run
- 2008, Aug - Complete data taking



Three years from
formation to
data taking complete!

Data taking & Data set



- Jun. 2007 – Aug. 2008
- 95% data efficiency

- 2.52×10^{20} POT in total
- neutrino : 0.99×10^{20} POT
- antineutrino: 1.53×10^{20} POT

**Preliminary results from
full neutrino data set
are presented**

Physics Analysis

Preliminary results

Physics Topics

Several analyses are in progress

- **C**harged **C**urrent
 - CC inclusive (ν_μ flux measurement)
 - CC-QE
 - CC- $1\pi^+$ → important for ν_μ disappearance
 - CC- π^0
 - CC- ν_e (ν_e flux measurement)
- **N**eutral **C**urrent
 - NC- π^0 → important for ν_e appearance
 - NC-elastic
- ν_μ disappearance

11 PhD students are working on analyses

Charged Current Charged Pion production

$$CC-1\pi^+$$

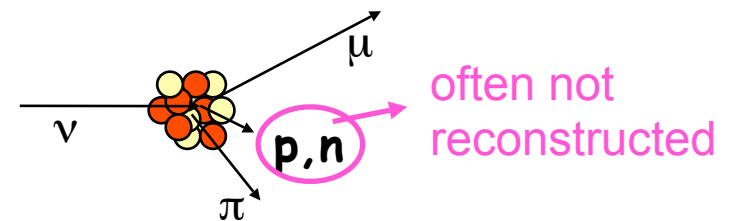
CC- $1\pi^+$ production

Charged current single charged pion (CC- $1\pi^+$) production

CC-resonant π production

Predominant process

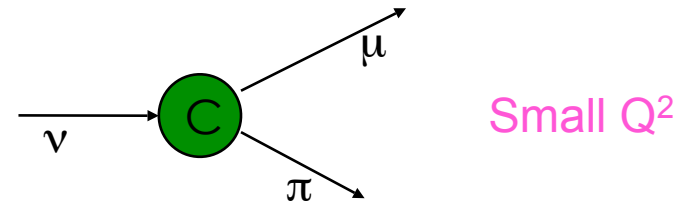
- $\nu + p \rightarrow \mu + p + \pi^+$
- $\nu + n \rightarrow \mu + n + \pi^+$



CC-coherent π production

ν interacts with nuclei coherently

$$\nu + C \rightarrow \mu + C + \pi^+$$



Signal event signature

2 MIP-like tracks (a muon and a pion)

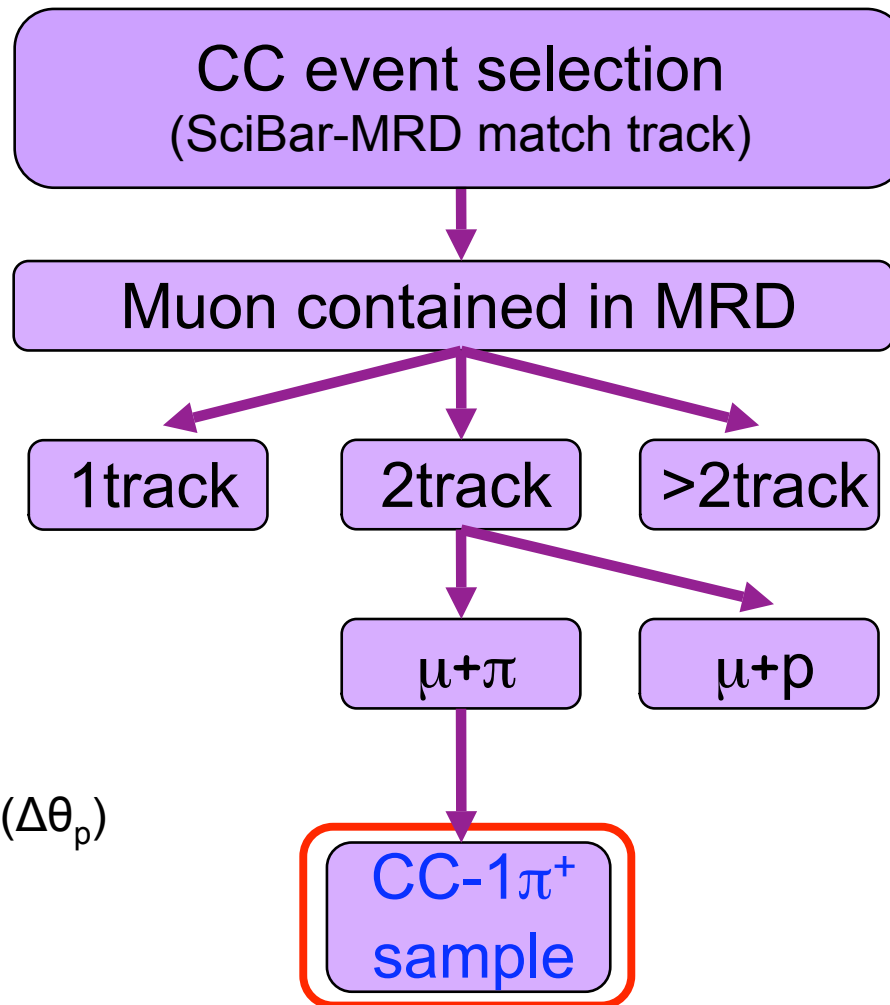
CC- $1\pi^+$ event selection

**Define MC
normalization**

Number of tracks
from a common vertex

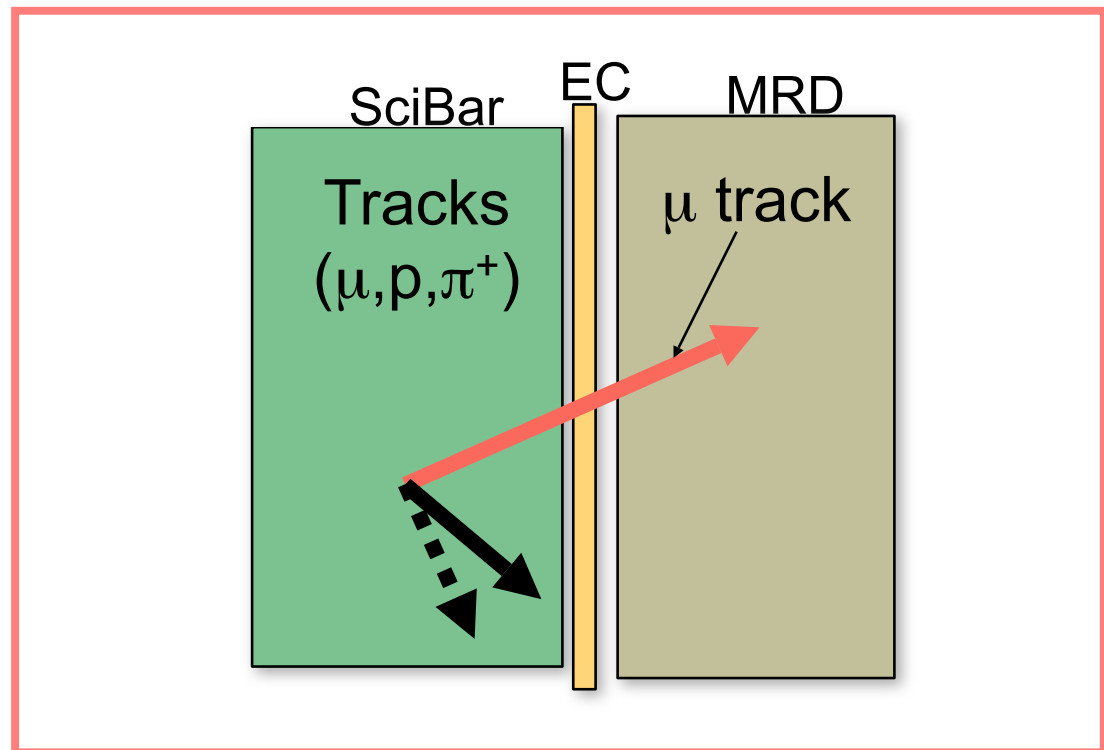
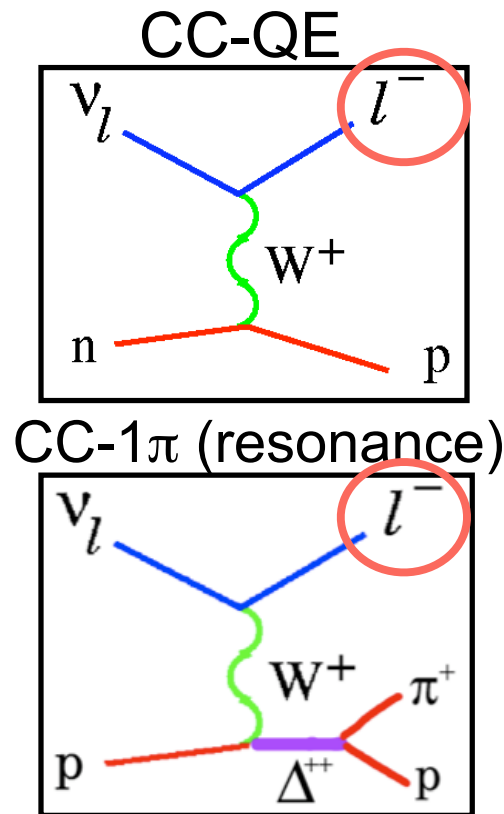
Particle ID using dE/dx

CCQE rejection using
non-muon track direction ($\Delta\theta_p$)



Signature of **CC** event at SciBooNE

- Muon = SciBar-MRD matched track



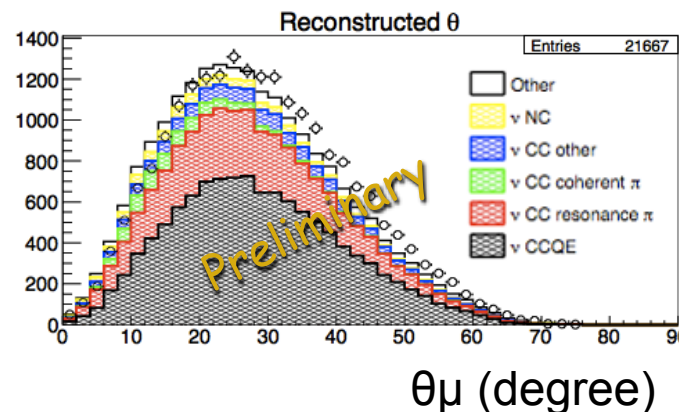
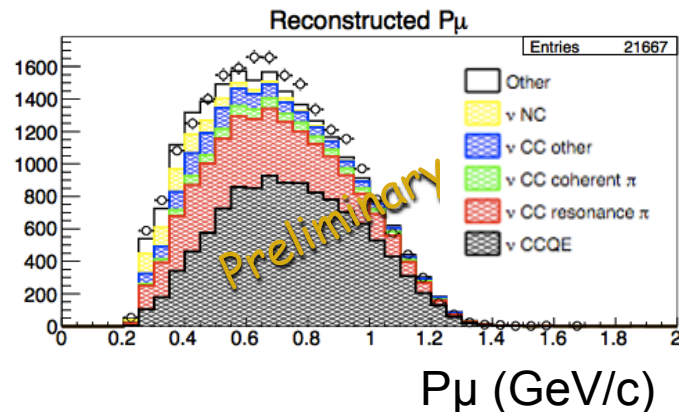
SciBar-MRD match sample:

- CC purity: 93%
- Cosmic ray background: <0.5%

CC sample

SciBar-MRD matched event: ~30k events

Muon kinematics of MRD stopped sample

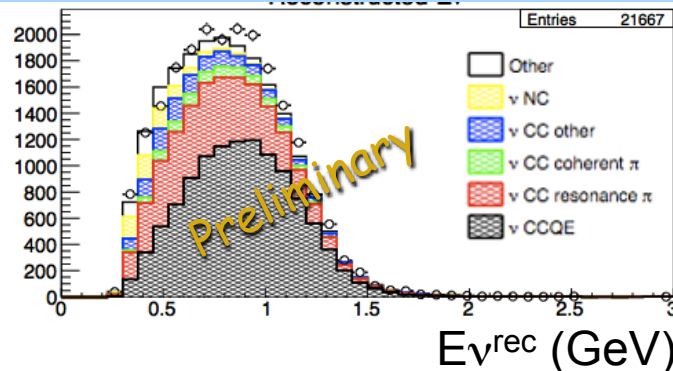


Y. Nakajima

$\sigma(P_\mu) \sim 50$ MeV/c
 $\sigma(\theta_\mu) \sim 0.9$ deg.

$M_A = 1.1$ GeV/c²

Reconstructed E_ν assuming CC-QE



CC purity: 93%

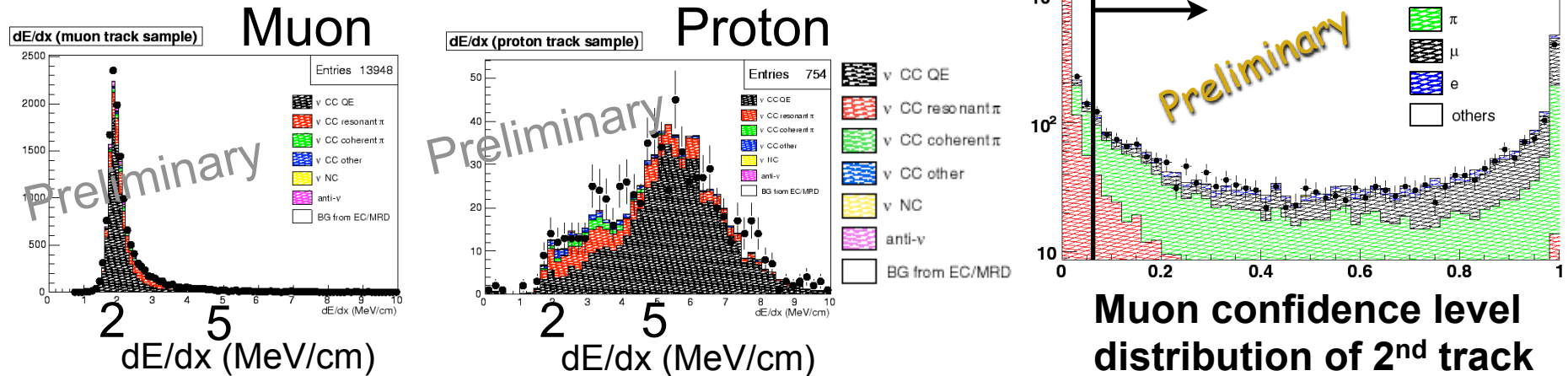
The sample is used to get
neutrino spectrum
for ν_μ disappearance search

MC is normalized to
SciBar-MRD matched sample

CC- $1\pi^+$ event selection

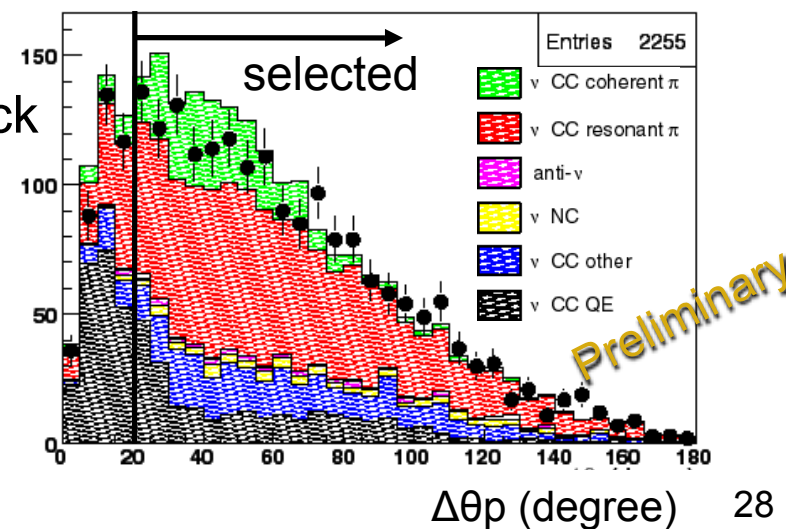
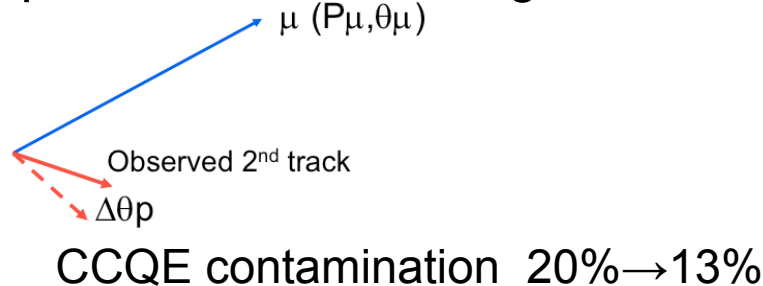
two MIP like tracks & CC-QE rejection

Particle ID based on dE/dx



CCQE rejection based on $\Delta\theta_p$

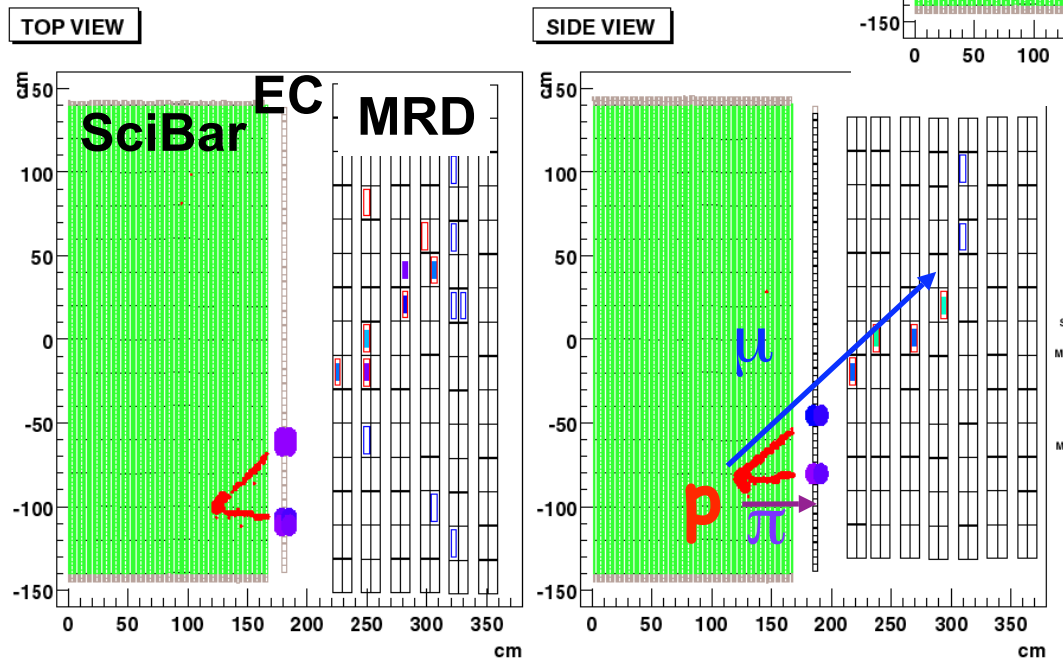
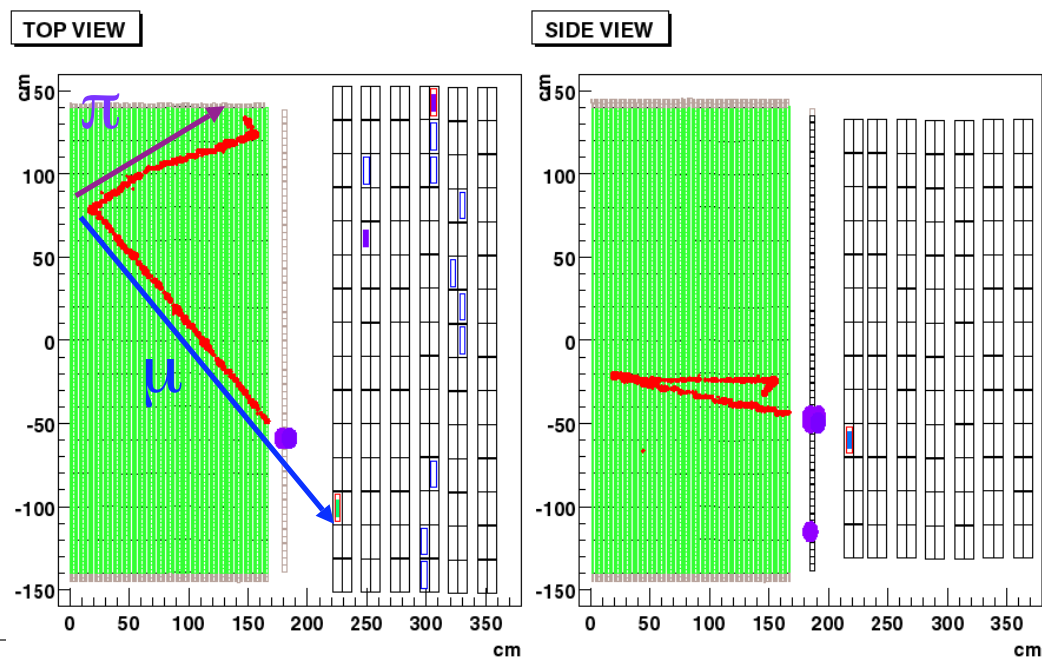
$\Delta\theta_p$: Opening angle between observed 2nd track and expected proton track assuming CCQE.



CC-1 π^+ selected events

SciBooNE
DATA

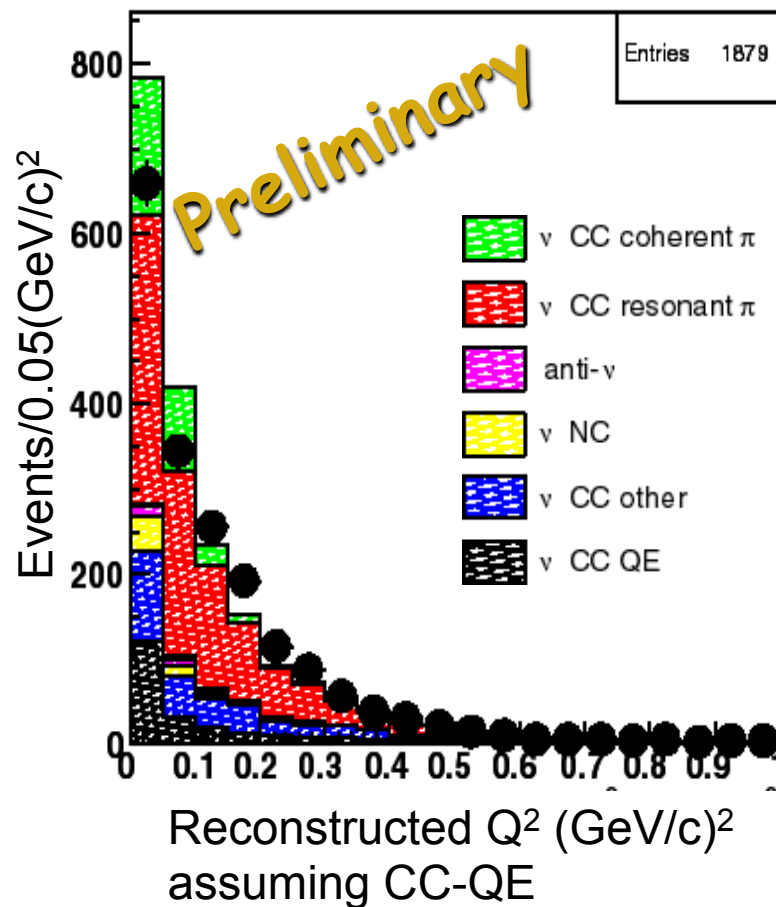
$\nu p \rightarrow \mu p \pi$ candidate



$\nu n \rightarrow \mu n \pi$ candidate

CC- $1\pi^+$ sample

Q^2 distribution



~80% pure $\mu^+\pi$ sample
CC- $1\pi^+$ fraction in the sample

$\nu p \rightarrow \mu p \pi$	34%
$\nu n \rightarrow \mu n \pi$	11%
CC-coherent π	15%

Observed DATA deficit
in low Q^2 region

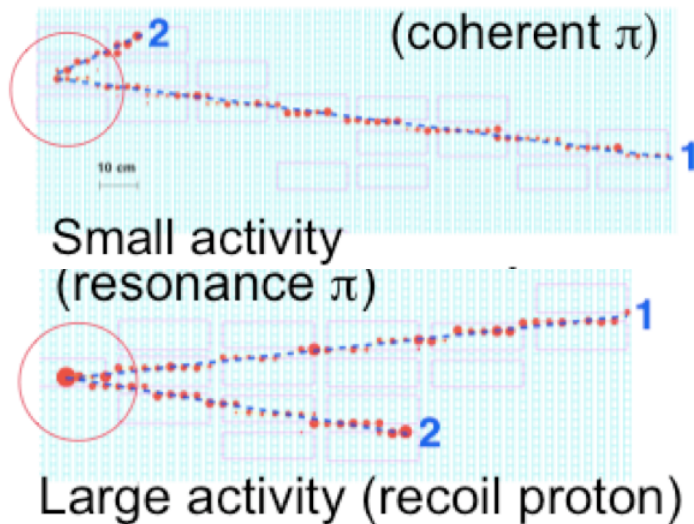
Separate CC-coherent π
from CC-resonant π
using its characteristic
kinematics

CC coherent π selection

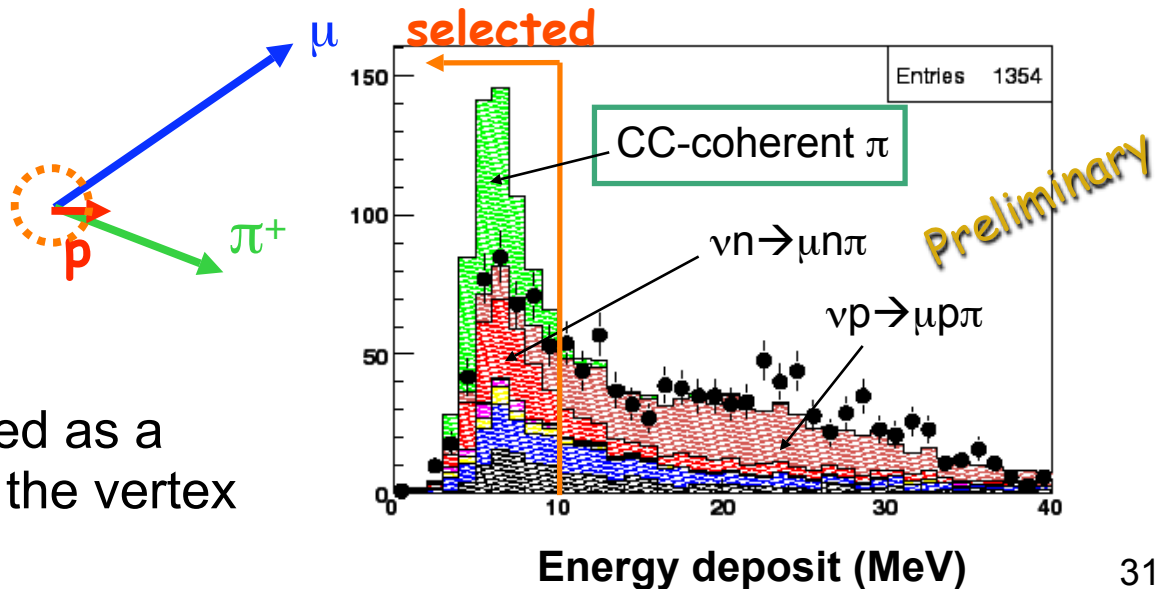
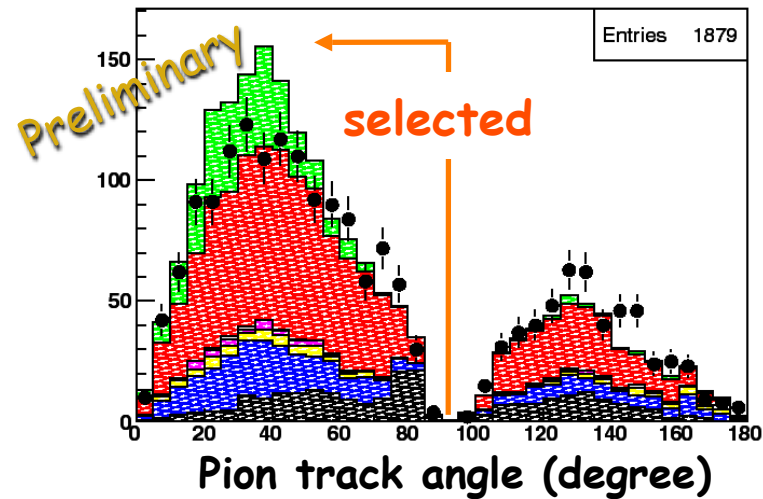
Direction of the pion track

Events with a forward-going Pion track are selected

Vertex activity

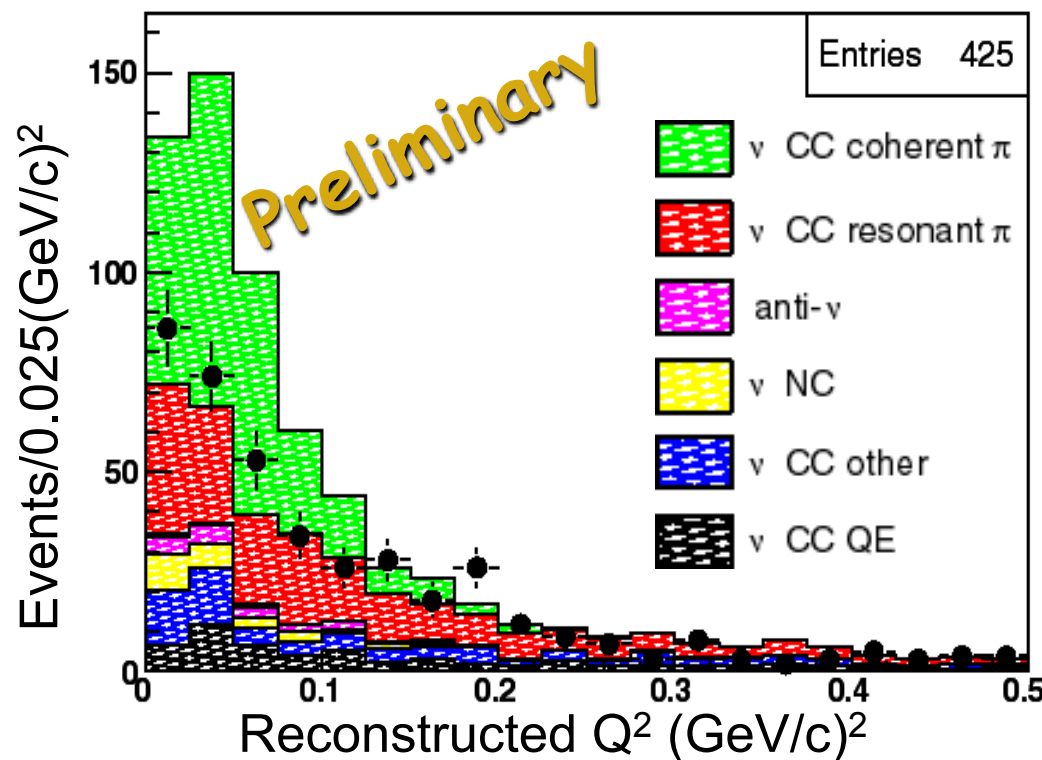


Low energy proton is identified as a large energy deposit around the vertex



CC coherent π sample

Q^2 distribution



CC-coherent π

Efficiency 13%

Purity 40%

* **Systematic error on background estimation is not included yet**

Observed CC-coherent π sample in SciBooNE contains fewer events than our MC simulation, which is based on the Rein&Sehgal model (2007)

SciBooNE sensitivity to $\sigma(\text{CC-coherent } \pi)/\sigma(\text{CC})$ ratio

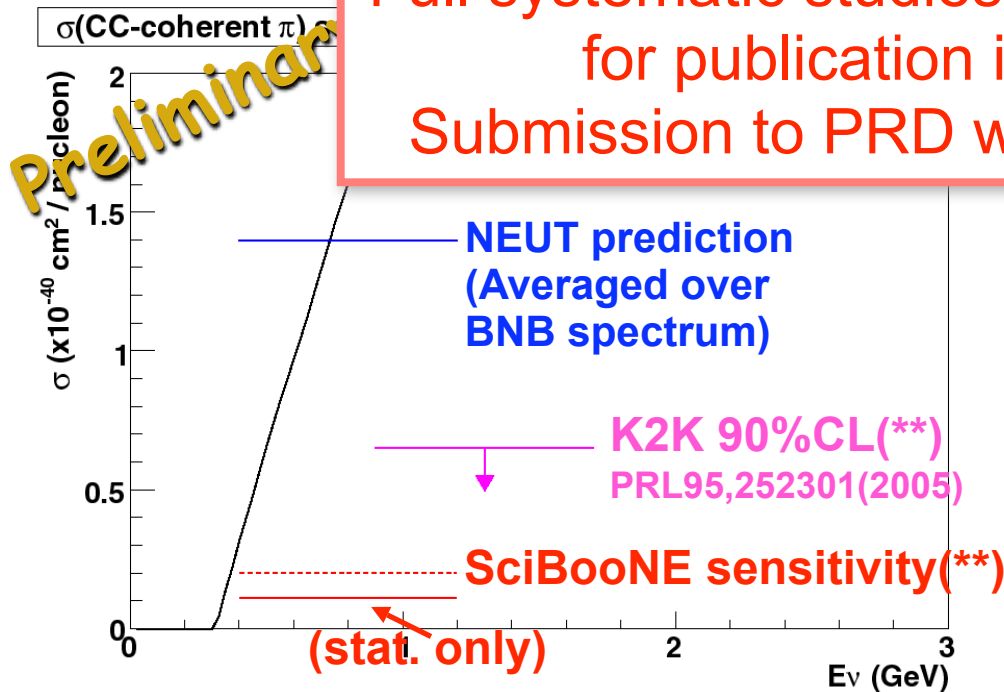
SciBooNE sensitivity

$$\sigma(\text{CC-coherent } \pi)/\sigma(\text{CC}) \sim 0.3 \times 10^{-2} (*)$$

(sensitive down to $\sim 10\%$ level of the MC prediction)

*In

Full systematic studies and paper drafting for publication in progress.
Submission to PRD will be next month.



tion ratio

MiniBooNE NC-coherent π^0

($\langle E_\nu \rangle \sim 0.8 \text{ GeV}$)

Phys.Lett.B664,41(2008)

(NC-coherent π)/(NC exclusive π^0)
 $= (19.5 \pm 1.1 \pm 2.5) \%$

65% of the Rein&Sehgal model

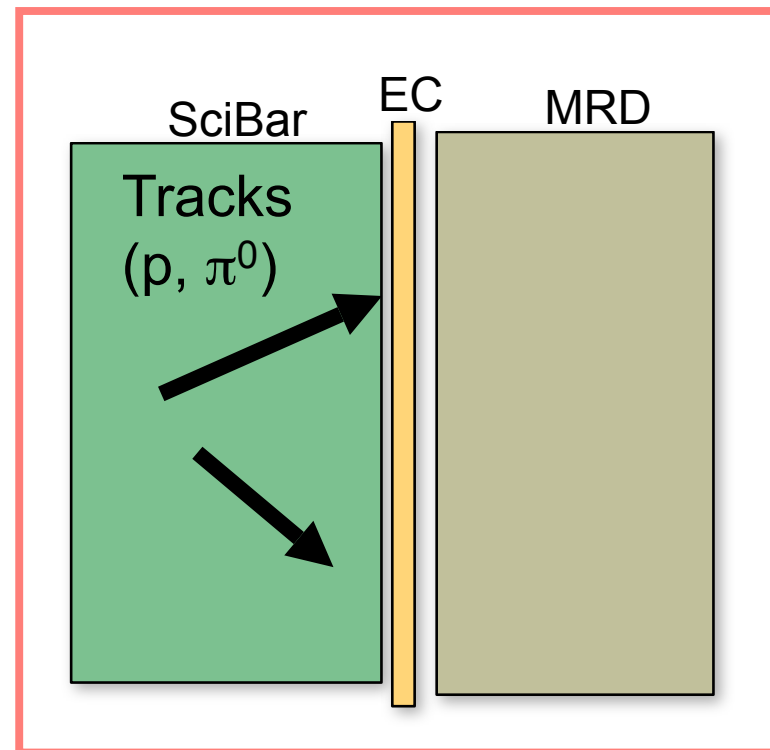
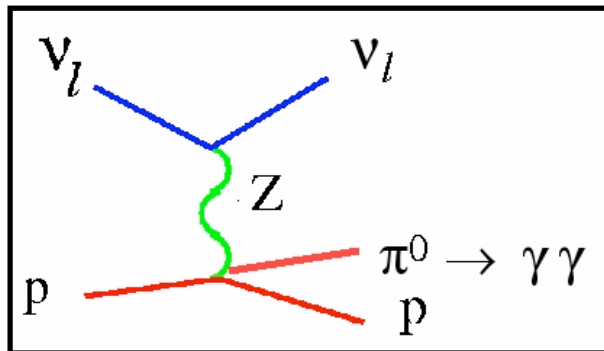
Neutral Current Neutral pion production

$$\text{NC-}\pi^0$$

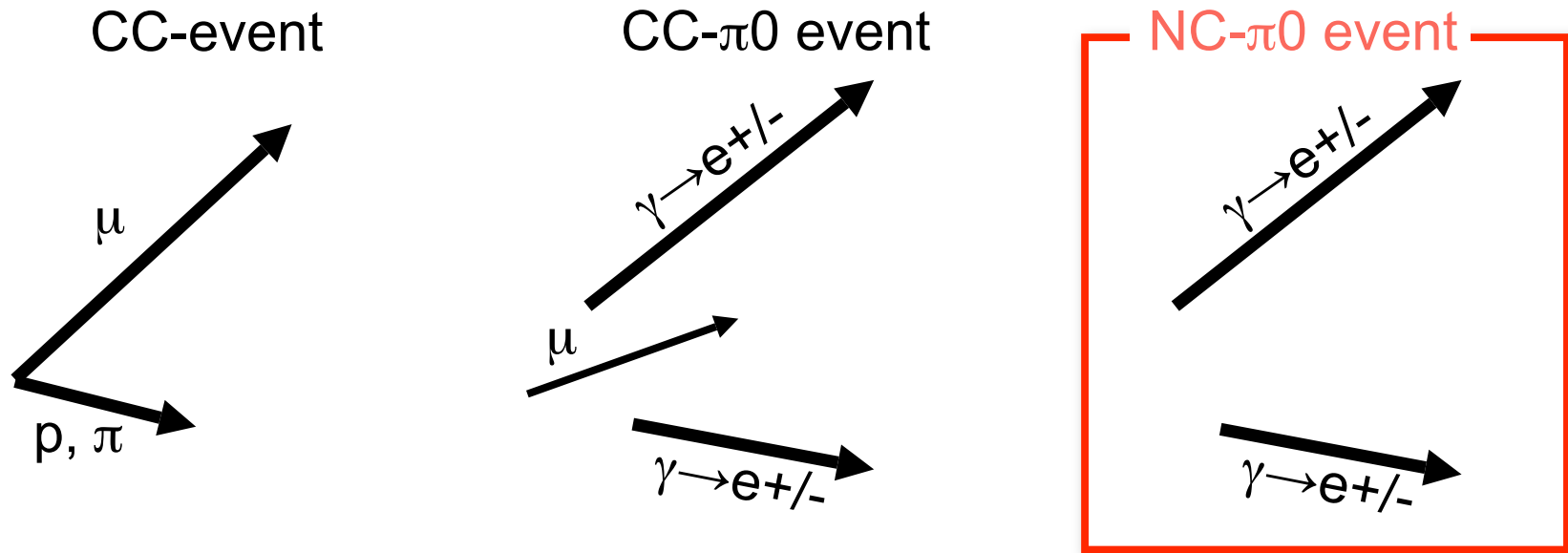
Signature of NC- π^0 event at SciBooNE

- No muon = No SciBar track go through MRD
- All tracks contained in SciBar

NC- π^0 : $\nu + N \rightarrow \nu + N + \pi^0$

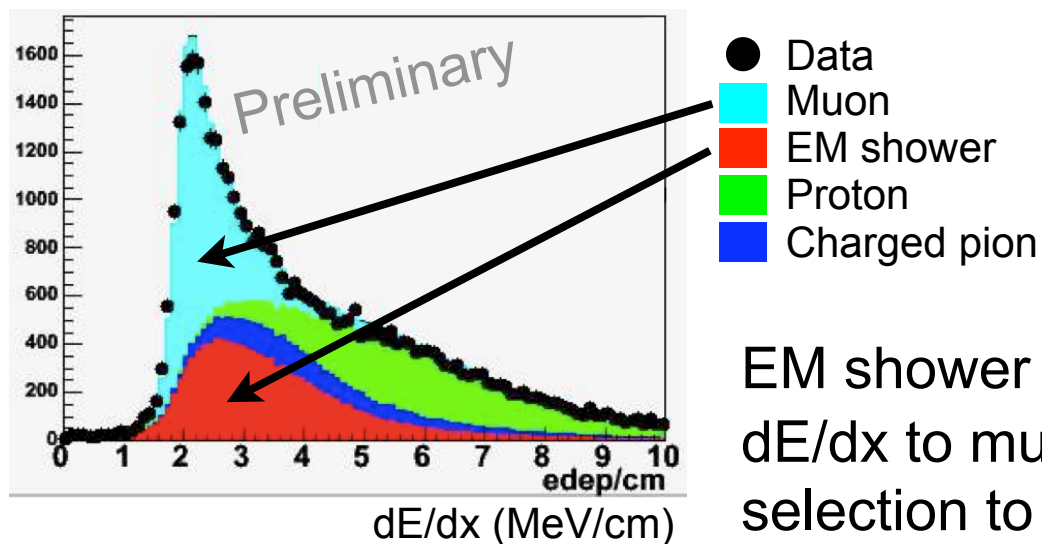
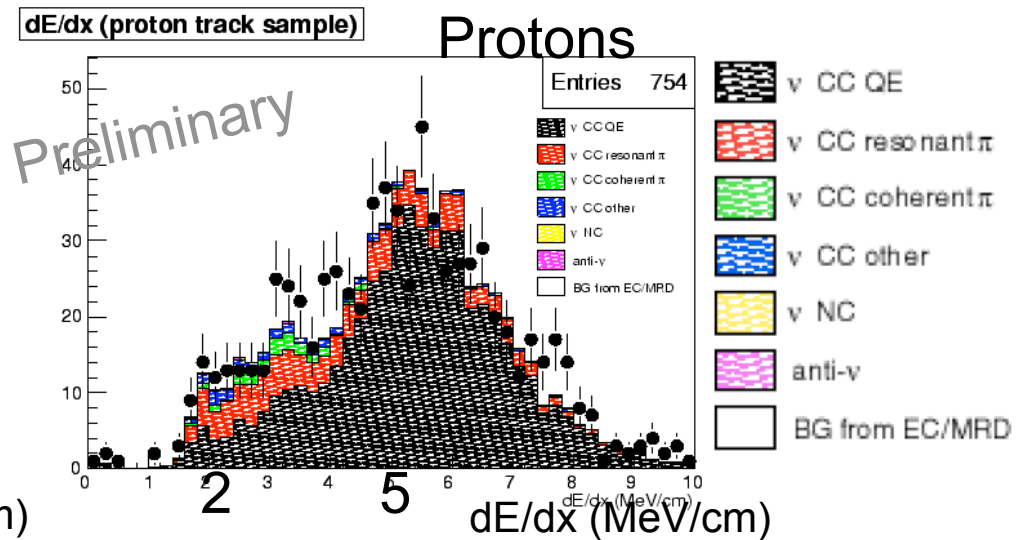
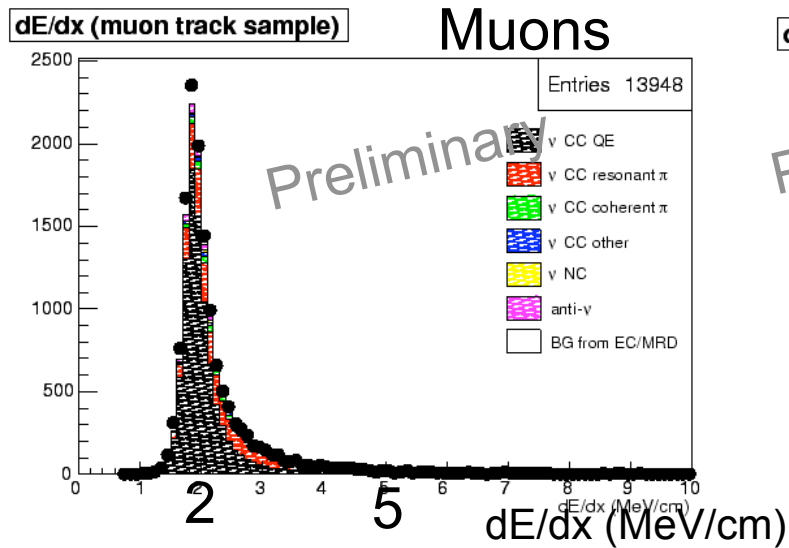


NC- π^0 event selection



- **NC- π^0 event selection**
 - Search γ tracks
 - **Particle ID -- Reject: μ, π, ρ**
 - Event topology
 - **Select two isolated tracks**

Particle ID with dE/dx

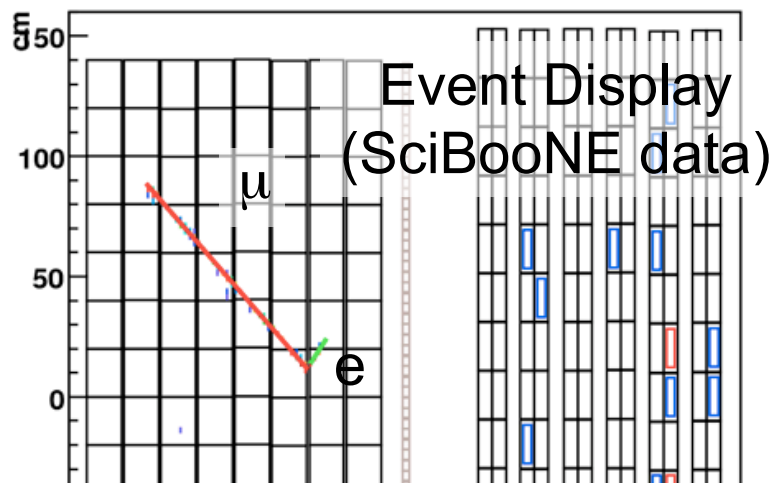


EM shower ($\gamma \rightarrow e^+e^-$) make similar dE/dx to muons. Need additional selection to reject muon (CC event)

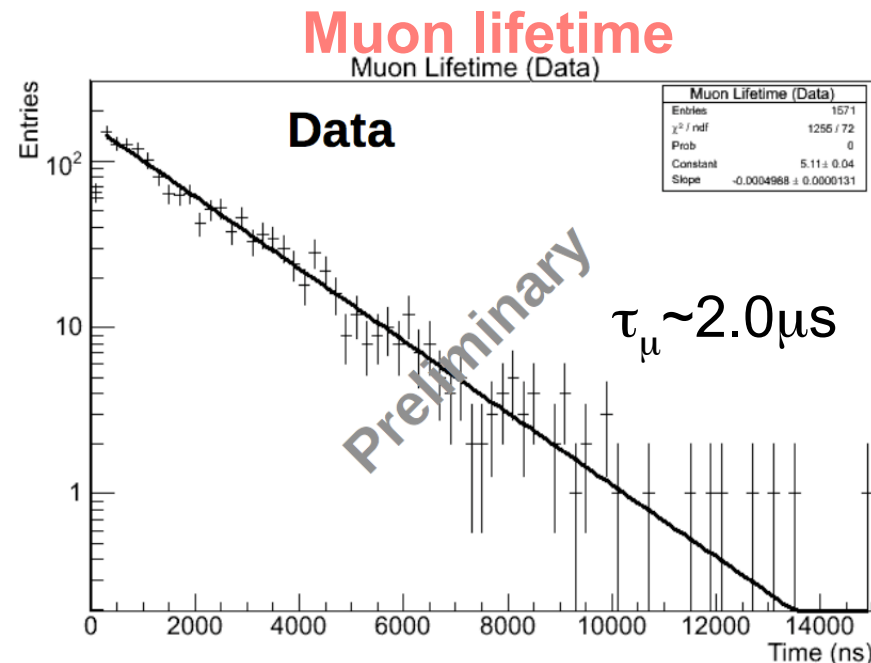
Particle ID with timing info:

Muon identification

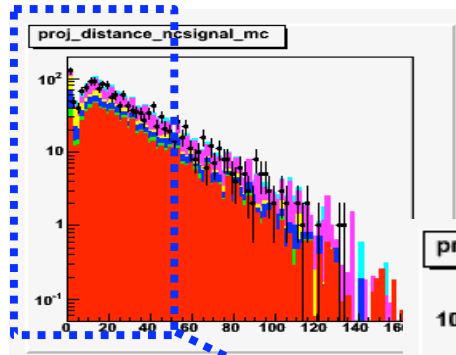
- Find out muon track → CC event rejection
- Tag decaying muon ($\mu \rightarrow \nu_s + e$) with SciBar TDC info: hits from muon and electron
- Clear signature of decaying muon.



Reject 66 % of decay-e events
Keep 95 % of no decay-e events



Event topology isolated tracks



Dot : data

CC w/o π^0

CC w π^0

NC w/o π^0

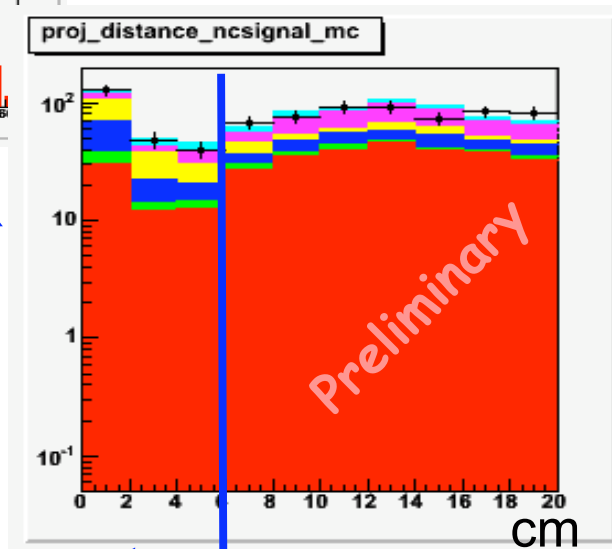
NC w π^0

Dirt

Cosmic

Internal

External



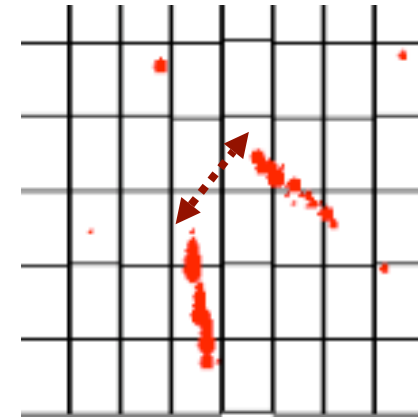
Reject
CC events

Threshold: 6cm

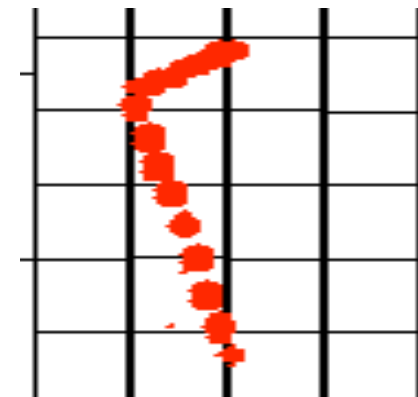
Signal efficiency (NC- π^0): 92%

Rejected 31% of CC events

Accept

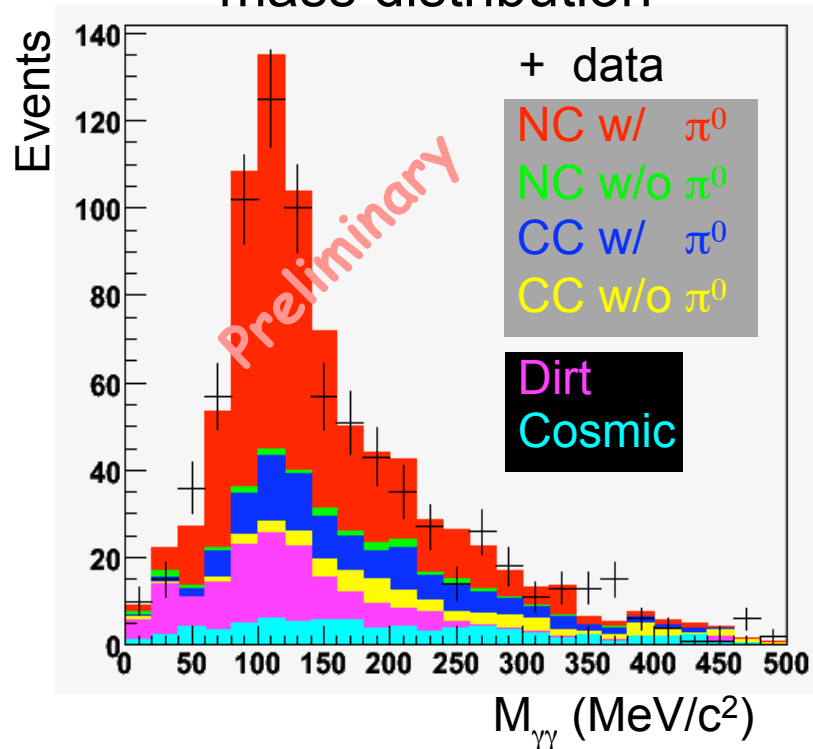


Reject



π^0 reconstruction

Reconstructed invariant mass distribution



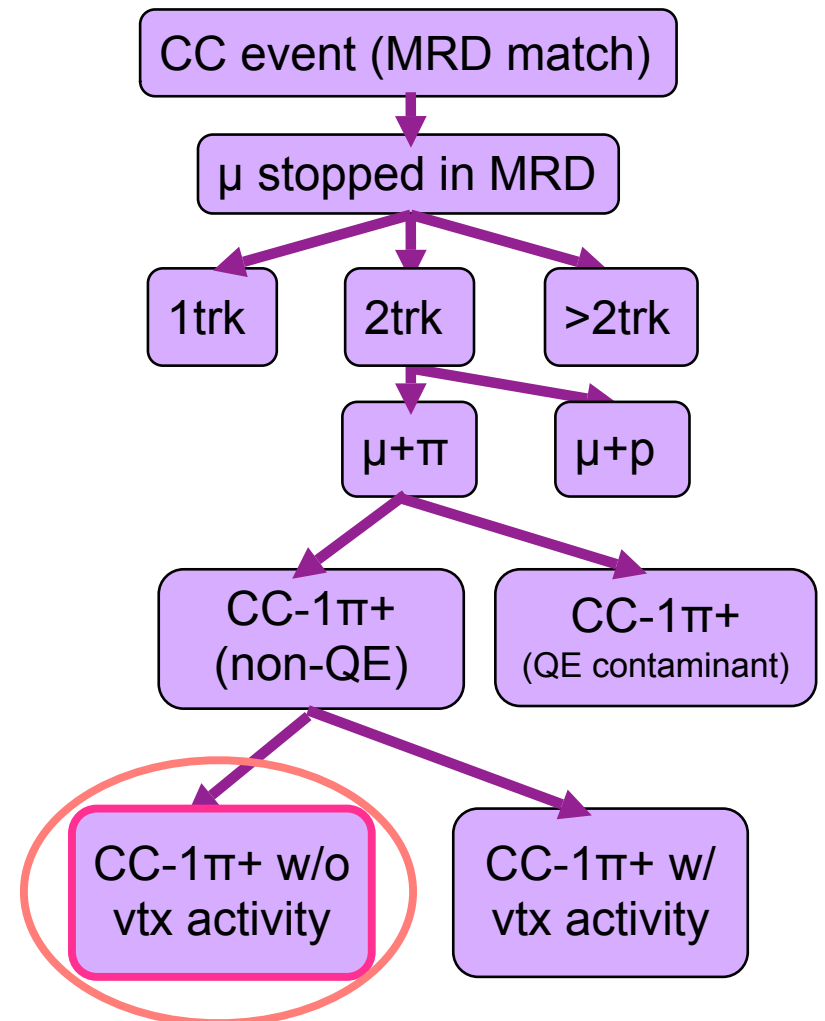
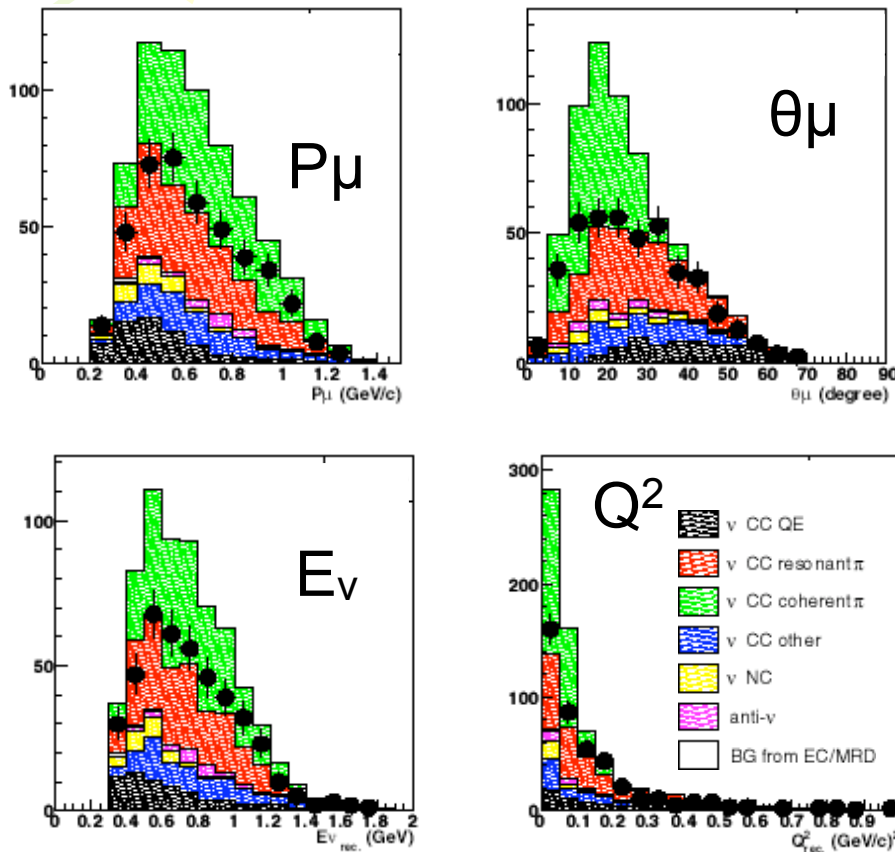
- Final selected sample
~850 events
 - NC- π^0 purity: ~54%
 - Clear π^0 mass peak only from π^0 produced events
- Cross section measurement

Summary

- SciBooNE measures neutrino and antineutrino cross sections near 1 GeV
 - Essential for future neutrino oscillation experiment
- CC- $1\pi^+$ measurement in SciBooNE
 - Observed fewer events in CC-coherent π sample than prediction
 - Full systematic studies and paper drafting for publication are in progress.
 - Submission to PRD will be next month.
- Many analyses are in progress
 - CCQE, CC π^0 , NC π^0 , NCelastic, ν_μ disappearance, ν_e measurement etc.
 - Antineutrino measurements
- Results will come soon

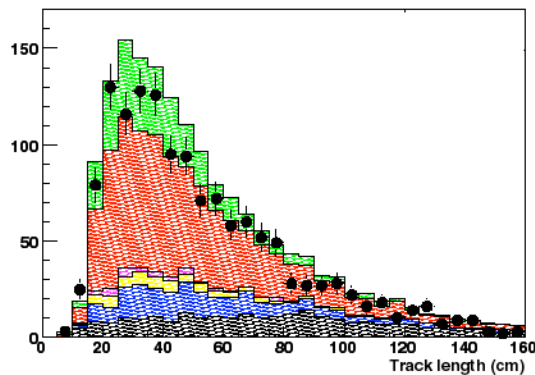
Backup

Other distribution in coherent sample

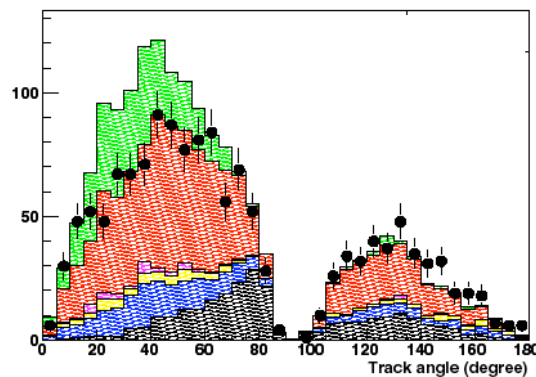


CC-1 π , non-QE sample

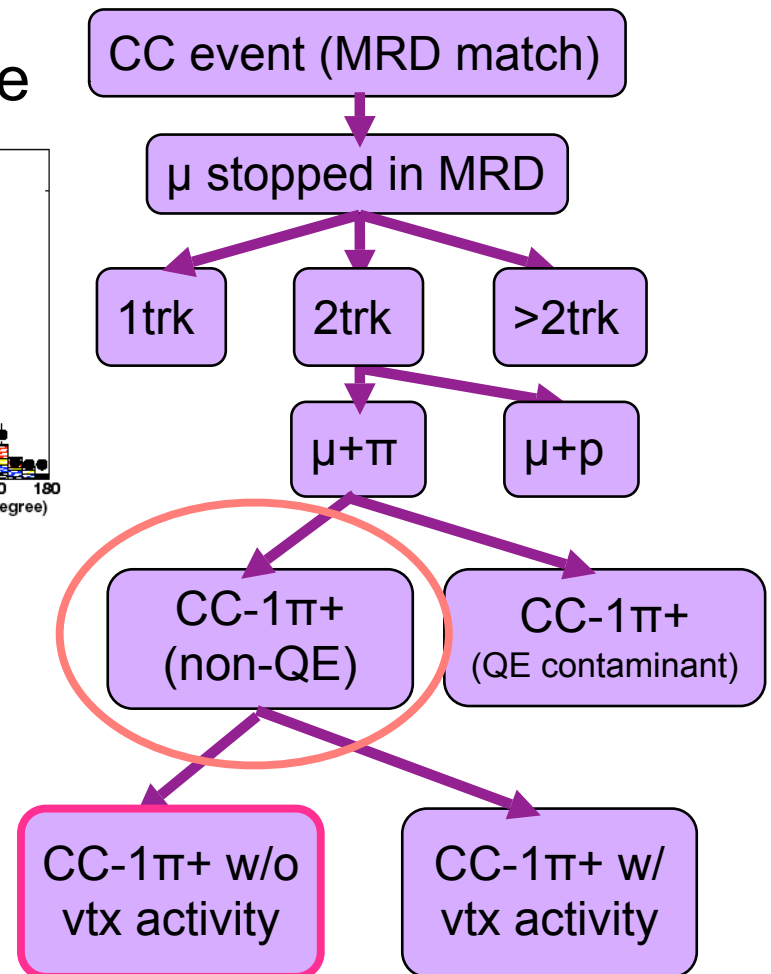
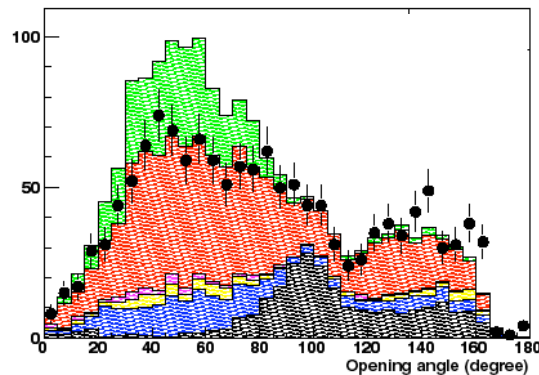
π track length



π track angle

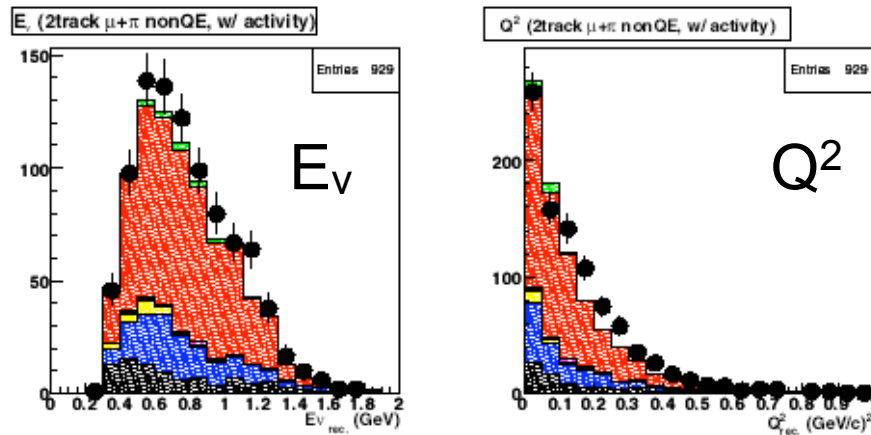


μ - π opening angle

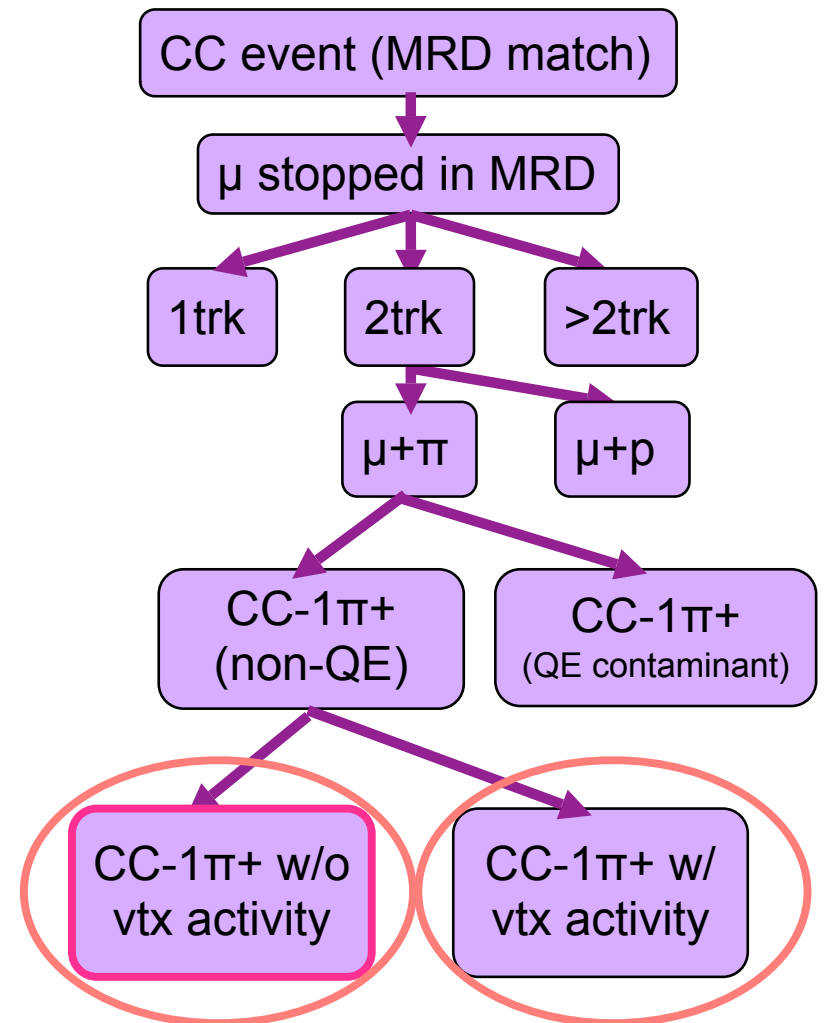
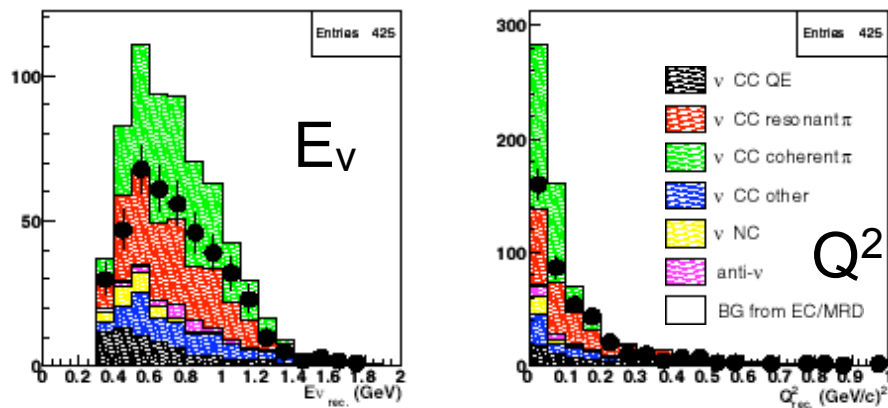


Comparison in samples

2trk, $\mu+\pi$, non-QE w/ activity

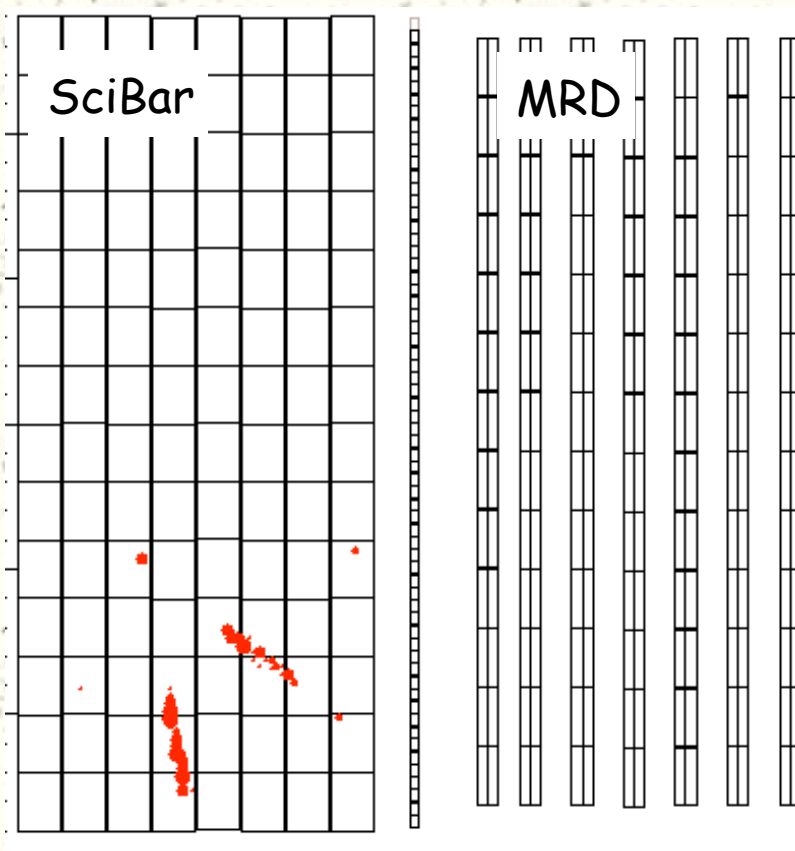


2trk, $\mu+\pi$, non-QE w/o activity



NC- π^0 signal & background

NC- π^0 candidate



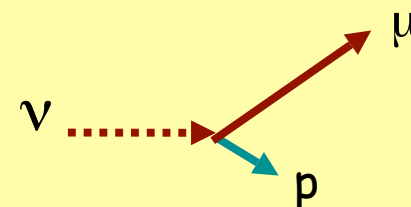
Experimental signature

2γ from π^0

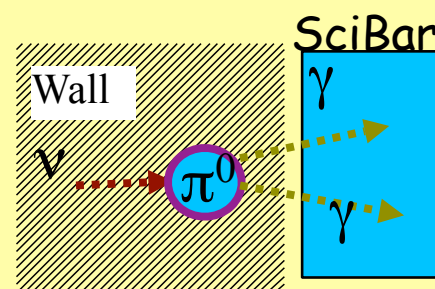
- 2 tracks in Fiducial Volume
- Disconnected
- Both tracks are not μ , p

Backgrounds

Internal BG
ex. CC-QE



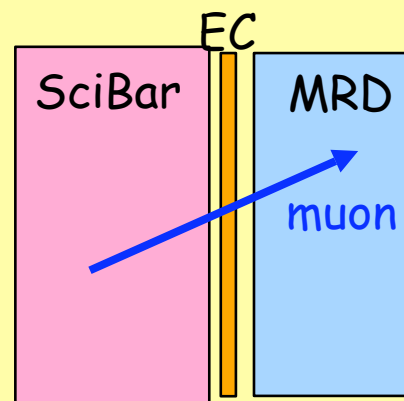
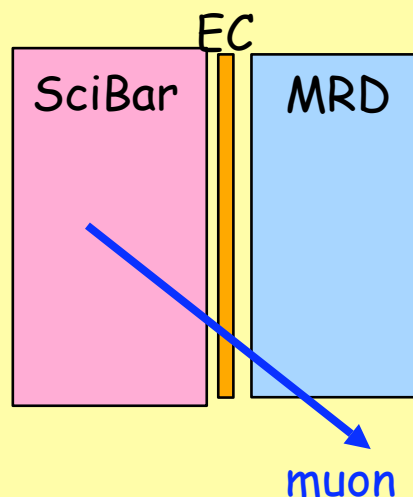
External BG
ex. Dirt



CC-inclusive sample

Neutrino energy spectrum measurement
using CC-inclusive sample

SciBar-MRD matched event (~30k events)



MRD stopped event (~22k events)
(muon contained in MRD)

93% pure CC-inclusive sample